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ELECTRIC LIGHT WIRING

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PREFACE

It has been the object of the author to present the subject treated in this book in such a manner as to make it intelligible to a person having a general knowledge of electricity, and to do this without sacrificing technical accuracy.

So far as the writer knows, the few books already published on the subject are either reprints of the National Electric Code, or more or less extensive amplifications of the same. The present volume contains data and information used by the author in his own practice; the greater portion of such data has never been published before, and it is believed will prove of considerable value to all interested in the subject.

In order to more clearly illustrate methods of designing electric wiring equipments, several practical examples are shown. These examples were selected from a list of several hundred installations designed in the office of C. O. Mailloux, E.E., and the author (Associated) Consulting Electrical Engineers.

It was at first intended to include a few chapters on the design of electric generating plants, and also on illumination, but in order to obviate delay in issuing this book, it was thought best to leave these subjects for some future time, particularly as the field of the last mentioned subject has broadened so wonderfully in the last year as to deserve separate and more extended treatment in a work devoted entirely to that subject.

Chas. E. Knox

February 25, 1907.

CONTENTS

Knox

The first point to be decided is the voltage of the lamps, or other appliances which are to be used. In the majority of cases, at the present time, particularly where the power requirements are not great, it is preferable to use a 120-volt lamp (i.e., a lamp of approximately 120 volts in contradistinction to a 240-volt lamp), and we will assume this to be the voltage and the lamp decided upon for the purpose of this discussion. We must also assume a given maximum percentage of loss, which we will allow in the feeders and mains. Let us assume this loss to be four per cent, and that we wish to transmit current a distance of 1000 feet, over a single feeder, for a total of 100 lamps to be of such candle-power as to require one ampere each.

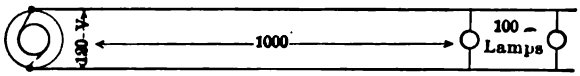


FIG. 1

Figure 1 shows these lamps arranged diagrammatically on a two-wire feeder, and Fig. 2 shows them arranged on a three-wire feeder.

In the first case the potential across the conductors is 120 volts. In the second case the voltage between either outside conductor and the neutral is 120 volts, and the voltage between

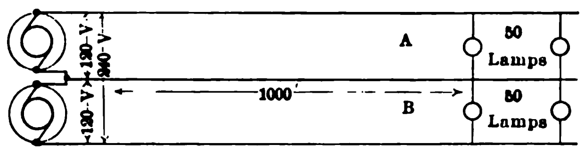


FIG. 2

the two outside conductors is twice that amount, or 240 volts (The method of obtaining the neutral potential is described later in this chapter.)

The neutral conductor is usually made at least equal in size to either of the two outside conductors, although for outside street mains it would be possible to make it smaller than the outsides; for interior wiring of buildings, however, the requirements of the National Electric Code stipulate that it should be made at least equal in size to the outside conductors. The weight in copper required to carry the given load (in this case 100 lamps) a given distance (in this case 1000 feet), at a given loss (4 per cent), will be

three eighths of that required to transmit that load, assuming the same distance and percentage loss as would be required to transmit it by the two-wire system.

It is evident that if the lamps could be so arranged in the case under consideration that 50 lamps were always connected on each side of the three-wire system, it would be possible to dispense with the middle conductor entirely, for the reason that the lamps could be divided in pairs and each pair of lamps could be connected in series with a potential of 240 volts across their outsides. As this is impracticable, however, in most cases, the neutral wire is required to carry the difference in current caused by more lamps being in use at times on one side of the system than on the other. For example, if there were 50 lamps in use on the upper side (A) of the system, as shown in Fig. 3, and

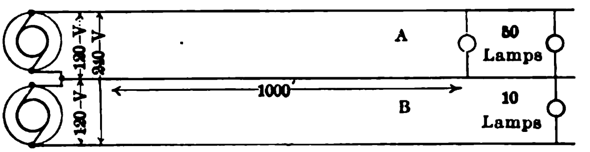


FIG. 3

only 10 lamps in use on the lower side of the system (B), the neutral conductor would have to carry the current for the difference between the two, or 40 amperes, the outside conductor (A) carrying 50 amperes and the outside conductor (B) carrying 10 amperes. The reason for this is that the ten lamps on the lower side would be practically in series with ten of the lamps on the upper side and this current would flow through the outside conductors only. The 40 amperes for the other lamps would, of course, have to flow through the upper and neutral conductors.

Now, let us figure the sizes of the wire required for the two systems, based on the load of 100 lamps, a distance of 1000 feet, and a loss of 4 per cent.

The formula for calculating this loss (see page 101) is as follows: the size of wire in circular mills is equal to the current in amperes, multiplied by the distance in feet (one way), multiplied by the constant 21.6, divided by the loss in volts, or

$$\text{c.m.} = \frac{I \times L \times 21.6}{E}$$

Let us first figure the size of the wire required for a two-wire

system. In this case, the current in amperes is equal to 100, distance (L) is 1000 and the loss (E) is 4 per cent of 120 volts, or 4.8 volts, substituting this in the formula given below

$$\text{c.m.} = \frac{100 \times 1000 \times 21.6}{4.8}$$

The result is that two conductors of 450,000 circular mils would be required.

So far as the maximum loss is concerned, the neutral wire (if made equal in size to the outside conductors) need not enter into the calculation at all, for the reason that the maximum loss would take place when all the lamps were connected to the circuit, at which time there would be a minimum (0) current flowing through the neutral conductor.

Now let us find the size of the conductors required for a three-wire system. In making this calculation it will not be necessary, as stated above, to consider the size of the neutral conductor. The current flowing through the outside conductors will be but 50 amperes, as the lamps are virtually arranged in fifty pairs, each pair being in series across the outside potential of 240 volts; therefore the current (I) will be but 50 amperes. The length in feet on each outside conductor will be the same as in the case of a two-wire feeder, but the loss in volts will be twice as great, for the potential is double, and 4 per cent of 240 volts is 9.6 volts. Substituting these values in the formula, we have

$$\text{c.m.} = \frac{50 \times 1000 \times 21.6}{9.6}$$

or the size of the conductor in circular mils required for each outside lead would be 112,500 (approximately No. 0 wire). If we made the neutral conductor equal in capacity to each of the two outside conductors, we would have three conductors of 112,500 circular mils required for a three-wire system, and two conductors of 450,000 circular mils required for a two-wire system.

As the weight of these conductors is proportional to their cross-section in circular mils, we can draw comparison as to the relative weights required by comparing their size in circular mils instead of their weight. Therefore, three conductors of 112,500 circular mils would be equivalent to 337,500 circular mils, and two conductors of 450,000 mils would be equivalent to

a conductor of 900,000 mils, and the relative weights of copper required would be

$$\frac{337,500}{900,000} = .375$$

or 37.5 per cent. That is, a three-wire system would require but three eighths of the weight in copper required for a two-wire system to transmit the current for the same number of lamps the same distance at the same percentage of loss, if the neutral conductor be made the same as either outside conductor.

It is, of course, evident that while the loss in volts in the three-wire system is twice as great as in the two-wire system, the variations in voltage at the lamp is the same as in a two-wire system, because the total variation in voltage is divided between the two sides.

Of course the size of the neutral wire may be varied according to the conditions, and the resultant saving in copper by the use of the three-wire system would be correspondingly affected. If the neutral wire, for example, were made one half the size of either of the outside conductors, the saving of copper effected by the three-wire system over the corresponding two-wire system would be greater, as only one fourth of the weight would be required for the former. It would be unsafe and would be contrary to the National Electric Code to make the neutral wire smaller than either of the outsides, for the reason that it would be possible, if in case a fuse blew, to have one side of the system fully loaded and to have no current on the other side. In this case, the neutral wire would be required to carry the same current as the outside wire, and this would probably overload the conductor if it were smaller than the outside conductors, and the percentage loss would be double. In some cases, however (as stated hereinafter), it is desirable to make the neutral equal to the combined capacity of the two outsides. In this case the saving in the weight of copper would be one half by the use of the three-wire system. Of course all of these calculations are made on the basis that when the three-wire system is used, the potential across the outside conductors is double that across the two-wire system and that the voltage of the appliances is the same in either case. Of course, a three-wire system is sometimes used where the potential is kept the same as in a corresponding two-wire system; this is done, sometimes, in an isolated plant having a potential of 120 volts, but where it is necessary or

desirable at times to take the current from the outside (240) volt three-wire mains. Of course, in such cases the calculation of the size of the feeder must be made on the basis of a voltage of 120, and as pointed out hereinafter, the three-wire system would be slightly more expensive than the corresponding two-wire system.

It should be understood that a saving in the weight of copper required does not necessarily mean a corresponding saving in the cost of the feeders and mains installed (including conductors, conduits, etc.), as the cost does not vary exactly in proportion to the weight of copper. For example, a No. 8 stranded conductor, having a high grade of rubber insulation, costs in the neighborhood of thirty-six dollars per 1000 feet. The cost of a No. 5 conductor (twice the size of No. 8) costs about fifty-six dollars per 1000 feet. Therefore, two No. 8 wires cost seventy-two dollars, or 29 per cent more than one No. 5 conductor. With the larger sizes the difference is reduced. Two 500,000 c.m. cables would cost approximately 9 per cent more than a 1,000,000 c.m. cable. It will be seen, therefore, it is absurd to figure the relative cost of two systems based solely upon the relative weights of copper required, particularly if the conductors are rubber covered, as the amount of insulation required for two small conductors is greater than that for one large conductor having the equivalent capacity of the two small conductors; furthermore, in a conduit system the total relative costs of the two systems is not proportional to the weights of copper.

Where the current is obtained from an outside source, or even where it is obtained from the generating plant in the building, but is liable to be taken from an outside source at any time, the wire should generally be adapted for the three-wire system. The reason for this is that the three-wire system, if properly laid out, can be adapted for any system of distribution (except the four-wire and five-wire systems, which are used abroad but not in this country). By making the neutral wire equal in capacity to the two outside wires combined, we can join the two outside wires and can transform it into a straight two-wire system. Where current is liable to be taken from either the plant in the building (when the plant voltage is one half the outside voltage of the street mains), or from the three-wire street system, this scheme should be adopted. When the current is taken entirely from an outside three-wire system, the feeders and mains in the

building should be three-wire; but all three conductors may be of the same size, provided the probability of a local plant being installed is slight.

For the description of systems of wiring where the current supply is alternating see page 109.

Of course, in large installations where the current supply might be taken at times from an outside source, as well as from the isolated plant, there is no economy in the use of the three-wire system, unless some means be used to obtain a neutral wire from the isolated plant system and the voltage of the isolated plant system be made the same as the outside supply.

In fact, if the isolated plant voltage were only equal to the voltage between the neutral and the outside conductor of the outside supply, the two-wire system would be more economical than the three-wire system. The reason for this is, that in such a case the neutral wire would have to be made equal to the combined capacity of the two outside wires, so that when current was taken from the isolated plant, the two outside wires could be connected together and the neutral would serve as the other conductor; the loss in the feeders would have to be figured for the lower potential of the two-wire isolated plant system, and the weight of copper required would be the same for the three-wire system as for the two-wire system, with the difference, that this weight would be divided into three conductors instead of two, as shown above. The cost of three conductors is greater than two conductors of the same weight, owing to the increased amount of insulation required and the greater cost of manufacture. The cost of connections, panels, switches, etc., would also be greater for the three-wire system in such a case. In some such instances, therefore, where large feeders are required (and if the central station manager permits), it may be advisable to use two-wire feeders and have them balanced across the outside three-wire system; some of the feeders might even be connected to double-throw switches so that they might be thrown on either side of the outside system. In most cases of this kind, however, it is probably wiser to use the three-wire system with the neutral equal to the combined capacity of the two outsides.

In the case of a large isolated plant, where the feeders are large and carry heavy loads, it may be very desirable to increase the pressure at which the current is transmitted, but at the same time not increase the voltage of the lamps or motors. To do

this, of course, necessitates the use of the three-wire system and the problem of obtaining the neutral current immediately presents itself. There are four practical solutions of this problem which are now used to a greater or less extent and, as the subject may assume considerable importance in some cases, these methods will be described somewhat in detail.

In the first system two separate and distinct generators driven by a single engine are used. Fig. 4 shows, diagrammatically,

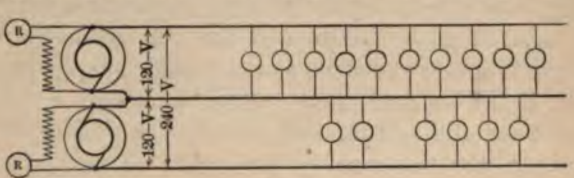


FIG. 4

the arrangement of this system. The disadvantages of this arrangement are (*a*) that the cost of these two generators is greater than would be the cost of a single generator of the same corresponding size; (*b*) the efficiency of the two machines is lower than a single machine, having a combined capacity of the two generators; and (*c*) the switchboard connections and the operation is somewhat more complicated than is the case of a single machine.

The advantage of this method is that great extremes of unbalancing can take place without injury to either the lamps or to the generators. The fields of these generators are separately controlled, and the voltage may be varied as desired. This method is applicable to very large plants only, and is practically limited to central station work. A plant of this kind was installed about eleven years ago in the Waldorf hotel, but it was later changed over so as to operate on a two-wire, 120-volt system.

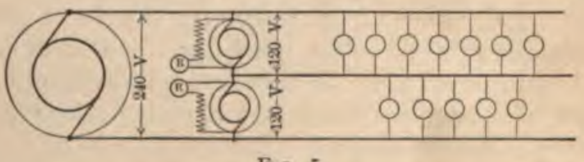


FIG. 5

In the second method (see Fig. 5) the generators are wound for 240 volts, in precisely the same manner as though they were to be used for a straight, two-wire, 240-volt system. The neutral

connection is provided by means of a separate motor generator set, operating across the two outside (240-volt) conductors. This motor generator or balancing set consists merely of two 120-volt motors having their armatures connected in series, the neutral wire being derived from the point at which the two armatures are connected. The shafts of the two motors are coupled mechanically together by means of a flange coupling, or similar device. When the system is evenly balanced, that is, when an equal number of lamps are placed on each side of the system, the balancing set merely acts in the same manner as two 120 motors, without load, connected in series across a 240-volt system. When the system becomes unbalanced, the machine connected to the side of the system having the lightest load operates as a motor and drives the other machine as a dynamo and supplies current to the heavily loaded side, thereby practically equalizing the load. It will thus be seen that either of the two machines may operate as either a motor or a generator, depending upon the balance of the system. As the shunt fields of each machine may be regulated separately, the voltage of either side of the system may be regulated as desired, within certain limits. But probably the best method to obtain close regulation by the use of balancers, is to have the latter differentially wound.

The size of the two machines constituting the balancing set will depend upon the amount of neutral current which is to be handled, that is, upon the maximum amount of unbalancing which is likely to take place on the system. In some cases this may not exceed, at any time, more than 5 per cent. In other cases it may amount to as much as 15 to 25 per cent. Where the amount of neutral current is not large, and where it is not necessary to run the plant twenty-four hours a day, this method is probably the most desirable. Its disadvantages are that there is a constant loss due to the fact that it is necessary to operate this balancing set continuously, and where it is necessary to handle a considerable amount of current in the neutral wire, the cost of the generating set would be quite large. The losses of operation of this balancing set include the power necessary to operate these machines as motors at full speed when the system is perfectly balanced, and also the I^2R (heat) loss and the hysteresis loss when the system is out of balance. Of course, in a system of any size, it would be necessary to have two sets of this kind in order to obviate a shut-down in the event of injury

to either of the two machines constituting the balancing set. In order to protect the balancing machines from injury, and the consequent burning out of the lamps through unbalanced voltage, it is usual to connect the circuit breakers in such a manner in the main line that they will open the entire circuit in case the balancing current exceeds the capacity of the balancing set.

In the third method (see Fig. 6) a single machine is used, in

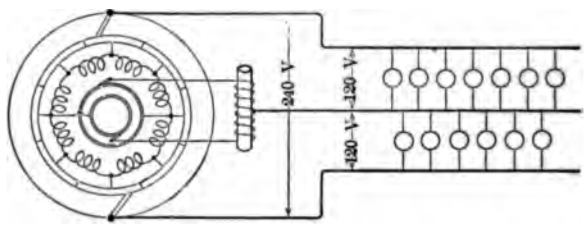


FIG. 6

conjunction with a compensating coil, or a set of compensating coils. This scheme is patented and generators of this type can only be made by two of the leading manufacturers of electrical machinery. As will be seen by an examination of the diagram (Fig. 6) the outside (240-volt) leads are taken from the generators at the commutator end in the usual manner. The third, or neutral wire, is derived from the central point of the compensator, the ends of which are connected between two points of the armature winding, dividing it into two equal parts. The connections at this end of the armature are made by means of collector rings, the same as in an alternating-current machine. By connecting the third conductor to the central point of the compensator a neutral potential will be obtained, which will serve for the neutral conductor in a direct-current, three-wire system, and will maintain a mean potential between the two outside conductors connected directly to the commutator.

The current in the neutral conductor is, of course, a direct current, although there is an alternating current passing through the compensator. When the current passing through the neutral conductor reaches the point at which said conductor is connected to the compensator, it chooses its path and during one small portion of a second passes through one side of the compensator back to the armature; the next small interval of time is divided between the two paths, and it then reverses and passes through the other side. At the time when the points of the armature

sections connected to the compensator are being commutated, the entire neutral current (i.e., the current carried through the neutral wire) passes through one side, (see Fig. 6), of the compensator; at the next interval of time, when the said armature sections are midway between the points of commutation, the potential at the two ends of the compensator is zero and the neutral current is divided, one half passing through each side of the compensator. When the armature sections are again being commutated (the polarity being reversed), the neutral current will pass entirely through the other side of the compensator.

The disadvantages of this system are (*a*) that it is usually only adapted for relatively small amounts of unbalancing; (*b*) that the cost of the generators is greater than for an ordinary generator, as it can be manufactured by but two companies, and (*c*) that there is no means of varying the potential on the two sides of the three-wire system, in order to compensate for unbalancing and thereby maintain a uniform potential at the lamps, unless a separate booster be employed. The advantages of this system are (*a*) that only a single machine is required, and for certain cases it is perhaps the best method on that account, and (*b*) that the losses in the compensator are relatively small.

The fourth method of obtaining the neutral current is by the

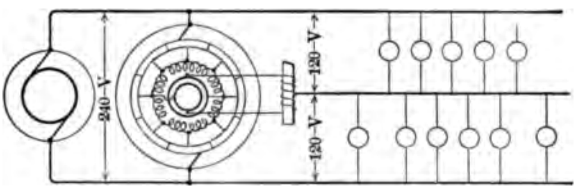


FIG. 7

use of a small rotary converter (see Fig. 7), operated across the two outside conductors as a direct-current motor, the neutral wire being connected to the middle point of a set of compensator transformers as in the third method; the compensators are connected to the collecting rings on the alternating-current end of the rotary converter. The phenomena is similar in this case to that described under the third method.

CHAPTER II

METHODS OF WIRING

THE methods of wiring now approved by the National Electric Code include the use of:

Rigid Conduits; Flexible Conduits; Armored Cables; Flexible Tubing; Knob and Tube Work; Cleat or Insulators; Moulding.

Each of these methods will be described separately in detail, and the rules of the National Electric Code which cover their use will be reproduced under the description of the corresponding method of wiring, as it is rather difficult to follow the rule relating to each method in the Code, owing to the unsatisfactory grouping and arrangement of the rules. The first five of the above methods are used for concealed wiring, and the last two, and sometimes the first also, are used for exposed wiring.

RIGID CONDUITS.

This method of wiring is approved by the Fire Underwriters, for all classes of buildings, for both exposed and concealed work. In the opinion of the author, it is the only method that should be used in new fire-proof buildings.

The requirements of a good conduit are first, it should be fire-proof. There is, as a matter of fact, no conduit in use to-day that does not fulfil this requirement. The reason for this is not hard to find, as there exists in every electric circuit for lighting or power the elements necessary to cause a fire, and every precaution should be taken to prevent the conduit from igniting and burning.

In the second place, it should be moisture proof. That is to say, it should be of such material or construction as to not absorb or hold moisture, and should be of such construction as would either prevent moisture from getting into the tube, or, if it be possible, to rid itself of moisture condensing in, or percolating through, the tube, by ventilation or by any other similar natural process.

In the third place the tube should be strong mechanically. It should resist nails, hard blows, and should not easily be flattened by being walked upon or by having wheelbarrows run over it. In the modern fire-proof building the conduits are subject to hard usage, as they are frequently installed before the flooring is placed over them. In the days of the old unarmored paper tube and of thin brass-armored conduit, great damage was frequently done in this manner to the conduits, and sometimes entire runs had to be replaced on account of flattened and damaged tubes.

Again, where the conduit is to be used in fire-proof buildings it is very desirable that the conduit should resist the action of cement. The inability to withstand the action of cement on the copper was one of the weak points of the old brass-armored conduit.

Again, the lining of the tube (if there be any lining) should be flexible, so that when the pipe is bent the conduit will not crack or break.

Lastly, the tube should withstand a "short circuit" on the wires which they contain, without disrupting.

Rigid conduits may be divided into two classes, namely: conduits with lining of insulated material, and unlined conduits, but having an inner coat of enamel, or similar material.

The unlined conduits consist of an iron or steel pipe, similar in size, thickness, and in every other way to gas pipe, except that special precautions are taken to free it inside from scale or any irregularities; it is then coated inside with enamel, outside it is sometimes enameled and sometimes galvanized.

The lined iron conduit usually consists of a plain iron pipe lined with a tube of paper which has been treated with an asphaltic or similar compound; this paper tube is cemented or fastened to the inside of the iron pipe so that it forms practically an integral part of the same.

The advantages of the unlined conduit over the lined conduit are, (1) it is cheaper, because having no lining a smaller size of conduit can be used for any given size of conductor, (2) it is also cheaper to install, as it can be bent, threaded, and cut more readily than the lined conduit, (3) and it is easier to insert and to withdraw wires, as the inside of an unlined (enameled) conduit is smoother than a lined conduit.

The principal disadvantages of the unlined conduit are (1)

that in fire-proof buildings, in case of injury to the outer iron pipe (corrosion, opening of pipe seam, etc.), the conductors may be exposed to the chemical action of ash cement, Keene cement, and moisture, etc.; (2) by the rules of the National Code, double-braided conductors must be used instead of single-braided conductors, which are allowed for lined conduit. The sole effect of this last objection is to slightly increase the cost of the conductors, but this effect is relatively slight compared with the decrease in cost of the unlined conduit itself and of installing it.

For all buildings or places where the conduit is not liable to corrosive action the unlined conduit should undoubtedly be used. In the latter cases it may be used, provided adequate effective means can be provided for preventing destructive corrosive action. As a matter of fact, with the improvement which has taken place in the manufacture of unlined conduit, the introduction of double-braided conductors, the use of insulating bushings at the terminals of all conduits (which prevent the conductors from resting on the bare pipe), and with improved methods of protecting the conduit from corrosive action, the unlined conduit may be used with much greater safety than heretofore. As soon as positive means have been found for the prevention of corrosion of the pipe, the unlined conduit will entirely disappear.

+ The rules governing the use of rigid conduits are as follows:

Construction of Rigid Conduits

Rule No. 49. (National Electric Code.) "Interior Conduits."

a. Each length of conduit, whether lined or unlined, must have the maker's name or initials stamped in the metal or attached thereto in a satisfactory manner, so that inspectors can readily see the same.

The use of paper stickers or tags cannot be considered satisfactory method of marking, as they are readily loosened and lost off in the ordinary handling of the conduit.

Metal Conduits with Lining of Insulating Material.

b. The metal covering or pipe must be at least as strong as the ordinary commercial forms of gas pipe of the same size, and its thickness must be not less than that of standard gas pipe as specified in the table given in No. 48. (National Electric Code.)

c. Must not be seriously affected externally by burning out a wire inside the tube when the iron pipe is connected to one side of the circuit.

d. Must have the insulating lining firmly secured to the pipe.

e. The insulating lining must not crack or break when a length of the conduit is uniformly bent at temperature of 212 degrees Fahrenheit to an angle of ninety degrees, with a curve having a radius of fifteen inches, for pipes of one inch and less, and fifteen times the diameter of pipe for larger sizes.

f. The insulating lining must not soften injuriously at a temperature below 212 degrees Fahrenheit and must leave water in which it is boiled practically neutral.

g. The insulating lining must be at least one thirty-second of an inch in thickness. The materials of which it is composed must be of such a nature as will not have a deteriorating effect on the insulation of the conductor, and be sufficiently tough and tenacious to withstand the abrasion test of drawing long lengths of conductors in and out of same.

h. The insulating lining must not be mechanically weak after three days' submersion in water, and when removed from the pipe entire must not absorb more than ten per cent of its weight of water during 100 hours of submersion.

i. All elbows or bends must be so made that the conduit or lining of same will not be injured. The radius of the curve of the inner edge of any elbow must not be less than three and one half inches.

Unlined Metal Conduits.

j. Plain iron or steel pipes of thicknesses and strengths equal to those specified for lined conduits in No. 49 *b* may be used as conduits, provided their interior surfaces are smooth and free from burs. In order to prevent oxidization, the pipe must be galvanized, or the interior surfaces coated or enameled with some substance which will not soften so as to become sticky and prevent the wire from being withdrawn from the pipe.

k. All elbows or bends must be so made that the conduit will not be injured. The radius of the curve of the inner edge of any elbow not to be less than three and one half inches.

Installation of Rigid Conduits

Rule No. 25. (National Electric Code.) " Interior Conduits."

(*See also Nos.* 24 *n to p, and* 49, *National Electric Code.*)

The object of a tube or conduit is to facilitate the insertion or extraction of the conductors and to protect them from mechanical injury. Tubes or conduits are to be considered merely as raceways, and are not to be relied upon for insulation between wire and wire, or between the wire and the ground.

a. No conduit tube having an internal diameter of less than five eighths of an inch shall be used. Measurements to be taken inside of metal conduits.

b. Must be continuous from outlet to outlet or to junction boxes, and the conduit must properly enter, and be secured to all fittings.

In case of underground service connections and main runs, this involves running each conduit continuously into a main cut-out cabinet or gutter surrounding the panel-board, as the case may be. (See No. 54.)

c. Must be first installed as a complete conduit system, without the conductors.

d. Must be equipped at every outlet with an *approved* outlet box or plate. (See No. 49 *l* to *o*.)

Outlet plates must not be used where it is practicable to install outlet boxes.

In the buildings already constructed where the conditions are such that neither outlet box nor plate can be installed, these appliances may be omitted by special permission of the Inspection Department having jurisdiction, providing the conduit ends are bushed and secured.

e. Metal conduits where they enter junction boxes, and at all other outlets, etc., must be provided with *approved* bushings fitted so as to protect wire from abrasion, except when such protection is obtained by the use of *approved* nipples, properly fitted in boxes or devices.

f. Must have the metal of the conduit permanently and effectually grounded.

It is essential that the metal of conduit systems be joined so as to afford electrical conductivity sufficient to allow the largest fuse or circuit breaker in the circuit to operate before a dangerous rise in temperature in the conduit system can occur. Conduits and gas pipes must be securely fastened in metal outlet boxes so as to secure good electrical connection. Where boxes used for centers of distribution do not afford good electrical connection, the conduits must be joined around them by suitable bond wires. Where sections of metal conduit are installed without being fastened to the metal structure of buildings or grounded metal piping, they must be bonded together and joined to a permanent and efficient ground connection.

g. Junction boxes must always be installed in such a manner as to be accessible.

h. All elbows or bends must be so made that the conduit or lining of same will not be injured. The radius of the curve of the inner edge of any elbow not to be less than three and one half inches. Must have not more than the equivalent of four quarter bends from outlet to outlet, the bends at the outlets not being counted.

Construction of Wires for Conduit Work

Rule No. 47. (National Electric Code.) " Conduit Wire."

a. Single wire for lined conduits must comply with the requirements of No. 41. For unlined conduits it must comply with the same require-

ments, — except that tape may be substituted for braid, — and in addition there must be a second outer fibrous covering, at least one thirty-second of an inch in thickness and sufficiently tenacious to withstand the abrasion of being hauled through the metal conduit.

b. For twin or duplex wires in lined conduit, each conductor must comply with the requirements of No. 41, — except that tape may be substituted for braid, on the separate conductors, — and must have a substantial braid covering the whole. For unlined conduit, each conductor must comply with requirements of No. 41, — except that tape may be substituted for braid, — and in addition must have a braid covering the whole, at least one thirty-second of an inch in thickness, and sufficiently tenacious to withstand the abrasion of being hauled through the metal conduit.

c. For concentric wire, the inner conductor must comply with the requirements of No. 41, — except that tape may be substituted for braid, — and there must be outside of the outer conductor the same insulation as on the inner, the whole to be covered with a substantial braid, which for unlined conduits must be at least one thirty-second of an inch in thickness, and sufficiently tenacious to withstand the abrasion of being hauled through the metal conduit.

The braid or tape required around each conductor in duplex, twin, and concentric cables is to hold the rubber insulation in place and prevent jamming and flattening.

Portion of Rule 24. (National Electric Code.) Wires.

For Conduit Work.

n. Must have an *approved* rubber insulating covering. (See No. 47.)

o. Must not be drawn in until all mechanical work on the building has been, as far as possible, completed.

Conductors in vertical conduit risers must be supported within the conduit system in accordance with the following table: —

No. 14 to 0 every 100 feet.
No. 00 to 4-0 every 80 feet.
0000 to 350,000 c. m. every 60 feet.
350,000 c. m. to 500,000 c. m. every 50 feet.
500,000 c. m. to 750,000 c. m. every 40 feet.
750,000 c. m. every 35 feet.

A turn of 90 degrees in the conduit system will constitute a satisfactory support, as per above table.

The following methods of supporting cables are recommended:

1. Junction boxes may be inserted in the conduit system at the required intervals, in which insulating supports of approved

type must be installed and secured in a satisfactory manner so as to withstand the weight of the conductors attached thereto, the boxes to be provided with proper covers.

2. Cables may be supported in approved junction boxes on two or more insulating supports so placed that the conductors will be deflected at an angle of not less than 90 degrees, and carried a distance of not less than twice the diameter of the cable from its vertical position. Cables so suspended may be additionally secured to these insulators by tie wires.

Other methods, if used, must be approved by the Inspection Departments having jurisdiction.

p. Must, for alternating systems, have the two or more wires of a circuit drawn in the same conduit.

It is advised that this be done for direct-current systems also, so that they may be changed to alternating systems at any time, induction troubles preventing such a change if the wires are in separate conduits.

The same conduit must never contain circuits of different systems, but may contain two or more circuits of the same system.

The above rules relating to wire refer specifically to wires for conduit work and for that reason are quoted here; the other rules covering wire are given in the chapter treating "Conductors."

Flexible Conduits

A distinction is usually made between flexible conduits and flexible tubing, the former being applied to metal tubes and the latter to non-metallic tubes.

Flexible conduit, as used to-day, consists of a continuous flexible steel tube, composed of convex and concave metal strips. These strips are wound spirally upon each other in such a manner as to interlock their concave surfaces, both exterior and interior, thereby securing a smooth and comparatively frictionless surface inside and out." This conduit is covered by the same rules of the National Electric Code as those covering rigid conduit. While it is approved for fire-proof buildings, it should not, in the opinion of the author, be used for such buildings.

The advantages claimed for this tube are continuity, flexibility, ventilation, and mechanical strength.

A continuous tube has a great advantage over a tube which comes in short lengths, as it avoids joints, couplings, etc., and can therefore be much more quickly installed. This conduit is made in coils of 50 to 200 feet, depending upon the diameter of the conduit.

The flexibility and continuity of this conduit make it possible to use it in many cases where other forms of conduit would be impracticable. Owing to these features it finds its greatest use in completed buildings where it is desired to install electric circuit work without greatly disturbing the walls, floors, or ceilings. This tube can be fished under the floors (in buildings of wood construction), in the partitions between the flooring and ceiling beams, by making pockets in the floors, walls, or ceilings, say every 15 to 20 feet (or nearer, in many cases), by "fishing" a stiff metal wire, called a "snake," through first, and then attaching the conduit either directly or indirectly to the fishwire and pulling the conduit in place. For vertical runs a chain, or similar device, is frequently used; the chain is dropped from the outlet to the floor and its lower end is located by the sound of the chain striking the floor.

The flexibility of this conduit dispenses with elbow fittings, as a bend of almost any radius can be made with this tube, with no other tools than the hands. But the greatest trouble may be caused by this flexibility, unless proper care be taken in in-

FIG. 8

stalling this tube. It is of the utmost importance that each tube be securely fastened in at least two, and preferably three, points at the elbow. If this precaution is neglected, it will make it very difficult, if not impossible, to pull the wire through the conduit, because the tube will buckle and assume such shapes as to cause it to effectually bind or grasp the conductor which is being pulled through the conduit. Fig. 8 shows the proper method of fastening this conduit at elbows and bends.

There is no doubt about this conduit being ventilated. If

smoke is blown through one end of a short length of this pipe it will all come out through the fissures between the spirals before it reaches the other end. In many places this would be an advantage, as, for example, in exposed work, or in places where it would not be concealed in cement or plaster. But it is very questionable that it is an advantage under tiled floors or in plastered walls where water might get in the pipe, and where the ventilation would be reduced to its lowest limits. In such cases as these there is no doubt that a solid pipe with leaded joints would be much dryer and better.

The tube is quite strong mechanically, although not absolutely nail proof.

Parts of this conduit and various devices used in connection with it are shown in Fig. 8.

This conduit is to be strongly recommended for use in frame buildings in place of knob and tube wiring or in place of flexible (non-metallic) tubing.

Armored Cable

The armored cable is made in a manner similar to the flexible steel conduit, but having the conduit made over the conductors.

Fig. 9

Fig. 9 shows an armored cable with twin conductors. This cable is perhaps better known as Greenfield Flexible Armored Conductor or "BX Cable." This armored cable is made with single conductors from No. 10 to No. 1 B. & S. gage; in twin conductors, from 14 to 8 B. & S. gage; and with 3 conductors from 14 to 10 B. & S. gage. It is also made with lead-covered single and twin conductors inside the armor of the same sizes. This lead-covered armored cable is very desirable for wiring on shipboard.

The rules of the National Electric Code governing the construction and use of this cable are as follows: —

24 A. Armored Cables. (**National Electric Code.**)

(*For construction rules, see No.* 48.)

a. Must be continuous from outlet to outlet or to junction boxes, and the armor of the cable must properly enter and be secured to all fittings.

In case of underground service connections and main runs, this involves running such armored cable continuously into a main cut-out cabinet or gutter surrounding the panel-board, as the case may be. (See No. 54.)

b. Must be equipped at every outlet with an *approved* outlet box or plate, as required in conduit work. (See No. 49 A.)

Outlet plates must not be used where it is practicable to install outlet boxes.

In buildings already constructed where the conditions are such that neither outlet box nor plate can be installed, these appliances may be omitted by special permission of the Inspection Department having jurisdiction, provided the armored cable is firmly and rigidly secured in place.

c. Must have the metal armor of the cable permanently and effectively grounded.

It is essential that the metal armor of such systems be joined so as to afford electrical conductivity sufficient to allow the largest fuse or circuit-breaker in the circuit to operate before a dangerous rise in temperature in the system can occur. Armor of cables and gas pipes must be securely fastened in metal outlet boxes so as to secure good electrical connection. Where boxes used for centers of distribution do not afford good electrical connection, the armor of the cables must be joined around them by suitable bond wires. Where sections of armored cable are installed without being fastened to the metal structure of buildings or grounded metal piping, they must be bonded together and joined to a permanent and efficient ground connection.

d. When installed in so-called fire-proof buildings in course of construction or afterwards, if concealed, or where it is exposed to the weather, or in damp places such as breweries, stables, etc., the cable must have a lead covering at least one thirty-second inch in thickness placed between the outer braid of the conductors and the steel armor.

e. Where entering junction boxes, and at all other outlets, etc., must be provided with *approved* terminal fittings which will protect the insulation of the conductors from abrasion, unless such junction or outlet boxes are specially designed and approved for use with the cable.

f. Junction boxes must always be installed in such a manner as to be accessible.

g. For alternating current, systems must have the two or more conductors of the cable enclosed in one armor.

This cable is somewhat smaller in diameter than the corresponding flexible conduit for the same sizes of conductors; it is, therefore, more easily installed in places where the space is limited. Furthermore, it can be more readily installed in completed buildings, as the conductors do not have to be drawn in afterward, as in the case of the flexible conduit. The armored cable, therefore, requires less cutting and damage to the floors and walls of a finished building.

However, while the armored cable is more easily installed

than the flexible conduit, and occupies less space, the conduit has the great advantage that wires can be withdrawn and new ones inserted. This advantage alone makes it preferable to use the conduit where it can be used.

Fig. 10

Flexible (Fibrous) Tubing

The use of this conduit is becoming more limited every year and as a separate method of wiring is only approved by certain inspectors. It is used in non-fireproof buildings and is frequently used in conjunction with other methods of wiring, such as knob and tube wiring, exposed wiring on insulators, molding work, etc. It is also used at the back of switchboards to cover conductors where they emerge from iron conduit, or where the conductors pass through walls, etc. It must be used on the loop system and be continuous, from outlet to outlet, or junction boxes, or other devices without tops; it must not be installed in damp places or in any way subjected to moisture (such as being placed in contact with damp mortar plaster, etc.). Wires should not be drawn into flexible tubing until after the rough work in the building is finished, as the tube is not strong mechanically and would not protect the wires from nails, etc. Duplex wires are not permitted in flexible tubing, although single-braided conductors are allowed.

Owing to the fact that this tubing is neither moisture proof nor mechanically strong, it compares unfavorably with the methods already described. It is, however, much cheaper than either the rigid or flexible conduit methods of wiring.

Figure 10 shows cut of flexible tubing.

Knob and Tube Work

This method of wiring is used for wiring houses of frame construction, where first cost is of the greatest importance. In this method the wires are run concealed under floors and in partitions supported on porcelain knobs and insulated, where they pass through floors and beams, by porcelain tubes. The knobs are used where the conductors run parallel to the beams and for vertical runs,

and the tubes are used where the wires pass through the beams or partitions, etc. Flexible conduits or porcelain tubes are used at outlets to protect the wires.

The rules of the National Electric Code, governing wires used for this work, are as follows: —

Conductors for Concealed "Knob and Tube" Work.

(Rules 24 *q* to 24 *u*.)

q. Must have an *approved* rubber insulating covering. (See No. 41.)

r. Must be rigidly supported on non-combustible, non-absorptive insulators which separate the wire at least one inch from the surface wired over. Must be kept at least ten inches apart, and, when possible, should be run singly on separate timbers or studdings. Must be separated from contact with the walls, floor timbers, and partitions through which they may pass by non-combustible, non-absorptive insulating tubes, such as glass or porcelain.

Rigid supporting requires under ordinary conditions, where wiring along flat surfaces, supports at least every four and one half feet. If the wires are liable to be disturbed, the distance between supports should be shortened.

Wires passing through timbers at the bottom of plastered partitions must be protected by an additional tube extending at least four inches above the timber.

s. When, in a concealed knob and tube system, it is impracticable to place any circuit on non-combustible supports of glass or porcelain, *approved* metal conduit or *approved* armored cable must be used (see No. 24 *t*), except that if the difference of potential between the wires is not over 300 volts, and if the wires are not exposed to moisture, they may be fished on the loop system if separately encased throughout in continuous lengths of *approved* flexible tubing.

t. Mixed concealed knob and tube work, as provided for in No. 24 *s*, must comply with requirements of No. 24 to *p*, and No. 25 when conduit is used, and with requirements of No. 24 A, when armored cable is used.

u. Must at all outlets, except where conduit is used, be protected by *approved* flexible insulating tubing, extending in continuous lengths from the last porcelain support to at least one inch beyond the outlet. In the case of combination fixtures the tubes must extend at least flush with outer end of gas cap.

This method of wiring should be discouraged as far as possible, as it is subject to mechanical injury, is liable to interference from rats, mice, etc. As the wires run according to this method are liable to sag against beams, laths, etc., or are likely to be covered by shavings or other inflammable building material, a

fire could easily result if the wires were overheated or if a "short circuit" occurred.

Figs. 11 and 12 show two forms of knobs, the solid knob and the split knob. With the former knob it is necessary to secure the conductors by means of tie wires; the split knob holds the conductor in position between the two portions of the knob. While the solid knob costs less than the split knob, the additional cost of the tie wires and the additional labor makes the cost about the same. The split knob is preferable as the conductor is more securely held in position.

FIG. 11

Fig. 13 shows details of knob and tube wiring.

Exposed Wiring on Cleats or Insulators

This method of wiring is used very extensively in mills, factories, and for heavy conductors for feeders, mains, etc., in tunnels and in other similar places.

Where the appearance of exposed wiring is not objectionable,

FIG. 12

this is one of the safest, cheapest, and best methods of wiring. In fact, if properly done, its appearance is far from objectionable.

The rules of the National Electric Code, governing this class of wiring, are as follows: —

FOR OPEN WORK.

(Rules 24 *g* and 24 *j*).

In dry places.

g. Must have an *approved* rubber or "slow-burning weather-proof" insulation. (See Nos. 41 and 42.)

A "slow-burning weather-proof" covering is considered good enough

where the wires are entirely on insulating supports. Its main object is to prevent the copper conductors from coming accidentally into contact with each other or anything else.

h. Must be rigidly supported on non-combustible, non-absorptive insulators, which will separate the wires from each other and from the surface wired over in accordance with the following table:

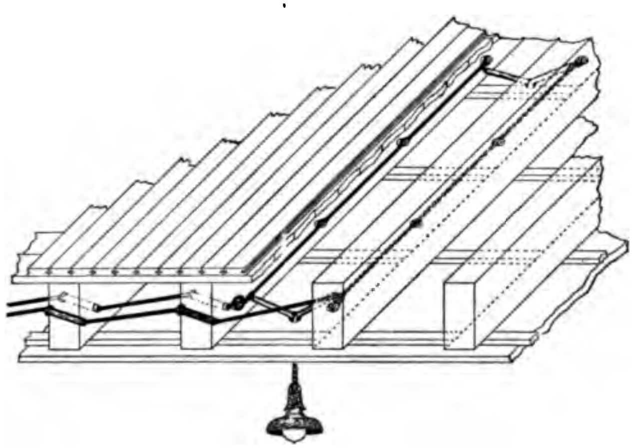


FIG. 13

Voltage	Distance from Surface.	Distance between Wires.
0 to 300	½ inch	2½ inches
301 to 550	1 "	4 "

Rigid supporting requires under ordinary conditions, where wiring along flat surfaces, supports at least every four and one half feet. If the wires are liable to be disturbed, the distance between supports should be shortened. In buildings of mill construction, mains of No. 8 B. & S. gage wire or over, where not liable to be disturbed, may be separated about six inches, and run from timber to timber, not breaking around, and may be supported at each timber only.

This rule will not be interpreted to forbid the placing of the neutral of an Edison three-wire system in the center of a three-wire cleat where the difference of potential between the outside wires is not over 300 volts, provided the outside wires are separated two and one half inches.

In damp places, or buildings specially subject to moisture or to acid or other fumes liable to injure the wires or their insulation.

i. Must have an *approved* insulating covering.

For protection against water, rubber insulation must be used. For protection against corrosive vapors, either weather-proof or rubber insulation must be used. (See Nos. 41 and 44.)

j. Must be rigidly supported on non-combustible, non-absorptive insulators, which separate the wire at least one inch from the surface wired over, and must be kept apart at least two and one half inches for voltages up to 300, and four inches for higher voltages.

Rigid supporting requires under ordinary conditions, where wiring over flat surfaces, supports at least every four and one half feet. If the wires are liable to be disturbed, the distance between supports should be shortened. In buildings of mill construction, mains of No. 8 B. & S. gage wire or over, where not liable to be disturbed, may be separated about six inches, and run from timber to timber, not breaking around, and may be supported at each timber only.

It will be seen from the above rule that the use of slow-burning, weather-proof wire is permitted in this class of wiring. This insulation consists of two or three layers of cotton braid, the inner braid being impregnated with a moisture-repelling compound, and the outer braid, or braids, with a fire-resisting compound. The advantages of this insulation are that it is extremely cheap and is indestructible. Of course, its insulation is not high and cannot be compared with rubber covering in that respect; in fact, so far as insulating qualities are concerned, these conductors should be treated as though they were bare and the insulation should be obtained by means of the supports to which the wires are secured. In passing through floors, partitions, walls, etc., the conductors should be protected by means of porcelain tubes or bushings; where the porcelain tubes or bushings are liable to mechanical damage, the tubes should be protected by iron pipes.

In some cases, the inspection authorities permit the use of flexible tubing placed in iron pipe for protecting exposed conductors passing through walls or partitions, but it is not to be recommended wherever it can be avoided, as the flexible tubing absorbs moisture, and grounds and leakage will take place, particularly where weather-proof and slow-burning insulated conductors are used.

Where exposed conductors run on the ceiling are liable to mechanical injury, as in low ceiling rooms, or where boxes or other materials are stacked on top of each other, the conductors should be protected by metal or wire enclosures, or in other similar manner. Where exposed conductors run on the side walls, they should be enclosed (see Rule 24 *e*, second paragraph) on the front as well as on the sides, for a length of not less than six feet from the floor, and higher in cases where they are par-

ticularly liable to danger. In damp places and under certain other conditions, rubber wire only is permitted for this class of wiring. It is, therefore, better to consult the local representative of the Inspection Board before using the slow-burning, weatherproof wire.

For small wires from No. 14 to say No. 6 B. & S. gage "cleats" are often employed for this class of wiring. A fairly good type of cleat is shown in Fig. 14. As will be seen from

FIG. 14

the cut, the cleat supports both wires, and in a three-wire system all three wires may be secured by the same cleat. The rules governing the construction of cleats are as follows: —

50 B. Cleats.

a. CONSTRUCTION. — Must hold the wire firmly in place without injury to its covering.

Sharp edges which may cut the wire should be avoided.

b. SUPPORTS. — Bearing points on the surface must be made by ridges or rings about the holes for supporting screws, in order to avoid cracking and breaking when screwed tight.

c. MATERIAL AND TEST. — Must be made of non-combustible insulating material, which, when broken and submerged for 100 hours in pure water at 70 degrees Fahrenheit, will not absorb over one half of one per cent of its weight.

d. MARKING. — Must have the name, initials, or trade-mark of the manufacturer stamped in the ware.

e. SIZES. — Must conform to the spacings given in the following table: —

Voltage.	Distance from Wire to Surface.	Distance between Wires.
0 to 300	½ inch.	2½ inches.

This rule will not be interpreted to forbid the placing of the neutral of an Edison three-wire system in the center of a three-wire cleat where the difference of potential between the outside wires is not over 300 volts, provided the outside wires are separated two and one half inches.

Care should be taken, in selecting the type of cleat, to avoid using one which will injure the wire; the cleat should also be strong mechanically and not liable to break in putting it up or afterward. As porcelain is quite brittle it is best to select robust designs or forms which are not made brittle by grooves or holes.

For damp places, or buildings subject to moisture or acid fumes, and for voltage over 300, the rules require the wires to be held at a distance of not less than an inch from the surface wired over; as cleats are not ordinarily made so as to keep the wires that distance from the surface, porcelain knobs must be used

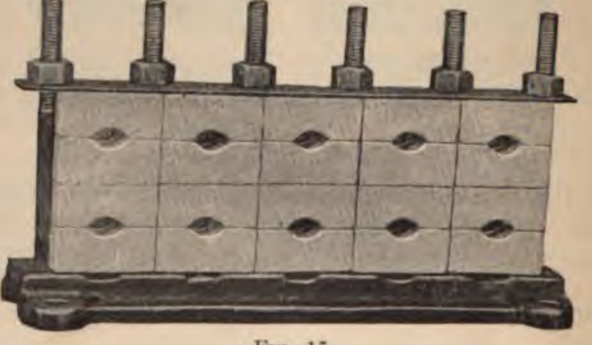


FIG. 15

instead of cleats for such cases. As a matter of fact, it is generally better and about as cheap to use knobs instead of cleats, and the split form should be used for the reasons already given under "Knob and Tube Wiring." Fig. 12 shows two good and popular forms of knobs. One of these knobs is designed to keep the wires 1 inch and another $\frac{9}{16}$ inch from the surface wired over.

For conductors of No. 4 B. & S. gage, and larger, insulators of the clamp, or preferably the rack type of insulator, should be used. Fig. 15 shows a clamp type of insulator. Care should be taken that the distance between the wires, and between the wires and the surface, comply with the rules.

For heavy feeders, and particularly where there are a number of feeders, the rack type should be employed. As this class of work is quite important we will discuss it somewhat in detail.

Conductors Run on Racks

The Conductor. — As already stated, a different kind of insulation may be used in this method of wiring than is used for concealed wiring. In the latter case the insulating covering of the wire must be depended upon entirely for the insulation of the feeder system; for even if there be an insulating lining in the conduit used, this should not be relied on to any great extent and should be considered chiefly as an additional protection. In the case of exposed work, on the other hand, we may, if we desire, depend entirely on the insulator for the insulation of the system. For this purpose, then, it is only necessary to have such a covering on the wire as will prevent trouble from actual short circuits, grounds, or such accidental contacts as might be caused by placing a metal bar, monkey wrench, etc., across the conductors or from other similar causes. The liability of this occurring may be greatly reduced by covering the conductors as a whole with wire lathing, galvanized sheet iron, or similar covering.

There are many kinds of insulating coverings which will accomplish this purpose other than rubber. Among these are the coverings used on the so-called weather-proof wire, and on the historic underwriters' wire. Even two or three wrappings of tape around the copper wire might suffice, although this would not be as durable and would probably cost just as much as either of the others. The weather-proof wire is best adapted for outdoor work, as it stands up well under changes of weather, moisture, etc. Its disadvantage is that it is not fire-proof. Underwriters' wire, on the other hand, is fire-proof, but is not as good for the purposes to which the weather-proof wire is best adapted. Where the feeders pass outdoors from one building to another, weather-proof wire would be better than either rubber-covered or underwriters' wire.

For ordinary inside work (not in damp places) a combination of underwriters' and weather-proof insulation called slow-burning weather-proof wire, is approved.

For extremely hot places and where there is danger of fire, slow-burning insulation is very satisfactory, but this wire should never be used without first consulting the local Inspection Authorities.

The rules (as revised in December, 1905) describing the construction of weather-proof, slow-burning and slow-burning

weather-proof conductors and the restrictions and recommendations relating to their use, are given in the chapter entitled, "Conductors."

Of course there are many cases where it would be unwise to use any insulation other than rubber for this class of work. The selection of one or the other depends on many conditions, and each case would have to be considered separately and a decision made according to the conditions. The point is, however, that in exposed work it is possible in some instances to substitute other insulating coverings for rubber and thereby make a considerable saving in the cost of the feeder system.

The Insulator. — In this connection this term designates the device insulating the conductor from the supporting hanger, rack, beam, etc. It is very rare that any material is used at the present time for insulators for interior wiring other than porcelain. Glass might be used, but it has many, if not all, of the disadvantages of porcelain for this purpose, and more beside, while its only important advantage is its lower cost. Porcelain for insulators has many advantages. It has high insulating qualities, it is not (when glazed) hygroscopic to any extent, it can be molded in a great variety of shapes and is cheap. Its great disadvantage is its fragility. Therefore, in adopting or designing a porcelain insulator for this class of work it is important to select such shapes and forms as will mitigate or avoid this weakness.

Briefly expressed, the insulator should be "chunky." In fact, this word best expresses the idea of the requirement to which all designs of insulators made of porcelain should conform in order to avoid breakage. Any form of insulator having thin projecting edges or lips, or which have been weakened by screw holes or grooves, should be discarded and stouter and more compact designs adopted. If this point be not strictly observed, there is bound to be trouble. I have known cases where a poor design of insulator has been used, and the breakage has been as high as 20 per cent.

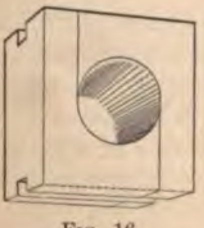


FIG. 16

Fig. 16 shows a good stout form of insulator for large wires. As will be seen from the drawing, this insulator is split so that while the wire passes through the center of the insulator, the insulator may be taken out at any time in case of breakage and be replaced by another.

The Insulator Rack, Clamp, or Holding Device. — For insulators of the type shown in Fig. 16, a frame or rack similar to the design shown in Fig. 17 is most suitable. This form of rack is more expensive than the form shown in Fig. 15, but it is more substantial and is better for very heavy conductors. As shown in the drawing, this consists of angle or T iron, to which are secured straps or bars of iron projecting outwardly, into which the slot in the insulator fits. On the outer side of the rack, each insulator is secured in place by separate straps, which at the same time serve to stiffen the rack. By removing any strap the corresponding insulator (and consequently the conductor) may be removed without disturbing the remainder. Where such strength and rigidity is not necessary, the horizontal straps on which the insulators rest may be replaced by $\frac{3}{8}$-in. or $\frac{1}{2}$-in. bolts of proper length for the size of the insulator. Of course there is no end to the variety of hangers or racks that might be designed for this purpose. In some instances many different shapes and sizes of racks are necessary for the same run of conductors in order to overcome peculiar conditions encountered in the course of the feeders. Each rack must, of course, be fitted and adapted for its particular location and requirement.

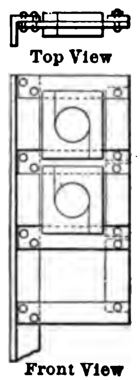


Fig. 17

Method of Supporting Rack or Hanger. — Where there are beams, girders, etc., to which the rack supporting the insulator may be fastened, it is easy to get a firm support for the racks. Beam clamps to which the racks are secured, may be used, or else the beams may be drilled and tapped and the racks fastened in place by stout machine screws. This makes a much more secure support than if the racks were screwed to wood, and also has the advantage of greater security in case of fire, a point which in many instances should be borne in mind.

When the insulating rack must be secured to a brick wall or ceiling, care should be taken to obtain a secure fastening. For this purpose expansion bolts, toggles, or some similar device should be used. Never depend on a wooden plug for a means of getting a fastening for a screw; sooner or later (generally sooner) these plugs are bound to get loose and pull out, even if the wood be seasoned. They are a "delusion and a snare," and are the more deceiving because they seem fairly firm when first put in the brick.

It is frequently necessary to stiffen or guy the racks where they are subject to any great strain owing to the pull or weight of the wires. This is especially true when the feeders change their course (as in turning a corner). For this purpose iron straps or stout steel wires may be fastened to the ceiling or wall at one end, and to the rack at the other end.

As far as possible a direct course or run should be selected for the feeders, for it is probably even harder to make bends or turns in exposed work than it is when the feeders are run concealed. Avoid crossing any pipes, ducts, etc., whenever possible. Steam pipes particularly should be avoided, as both weather-proof and rubber insulation are affected by high temperatures. The conductors should not be allowed to rest or touch anything but porcelain (if they have weather-proof or fire underwriters' insulation) throughout the entire course.

When the route has been selected, the start should be made at the switchboard, for there is the greatest congestion and there the greatest ingenuity must be exercised in order to obtain satisfactory results. In most cases the switch with which a given feeder must connect is prescribed, and this makes it all the more essential to start at the board in order to avoid crossing to make the proper connections.

In all cases where the feeders are large or numerous it is well to make a small working model of the feeder system, using small wire or cord for wires, and pasteboard for racks. It is much easier handling No. 18 wire than 1,500,000 c.m. and cardboard than iron. Then when the course has been properly mapped out the racks should be set in place throughout the entire course. When the insulator used is of the type shown in Fig. 16, one half of each insulator for each feeder should be set in place in the rack, the conductor then being laid on this half and then the remaining half of the insulator put in place, and then the straps should be fastened in position. This is a much quicker method than pulling the wires through the insulator and also avoids abrasion. Where it is necessary to pass through walls, partitions, etc., the wires should be protected (unless covered with rubber) by porcelain sleeves or tubes (preferably split in two parts), which are properly protected from breakage. If the conductors be insulated with rubber, sections of lined conduit may be used.

Figure 18 shows an example of medium-sized feeders rising from a switchboard to the ceiling. In this case the voltage of

the installation was 240 volts and rubber-covered wire was used. The insulators were the ordinary porcelain "knobs," fastened by machine screws to channel iron, which in turn was fastened to the iron frame of the partition. The wires were "tied" in the regular manner to the outside of the insulator.

Figure 19 shows a view of very heavy feeder conductors. In this case the insulator used is of the form shown in Fig. 16, rack being of the design shown in Fig. 17. The wire is triple-braided, weather-proof. Fig. 20 shows another view of the same installation.

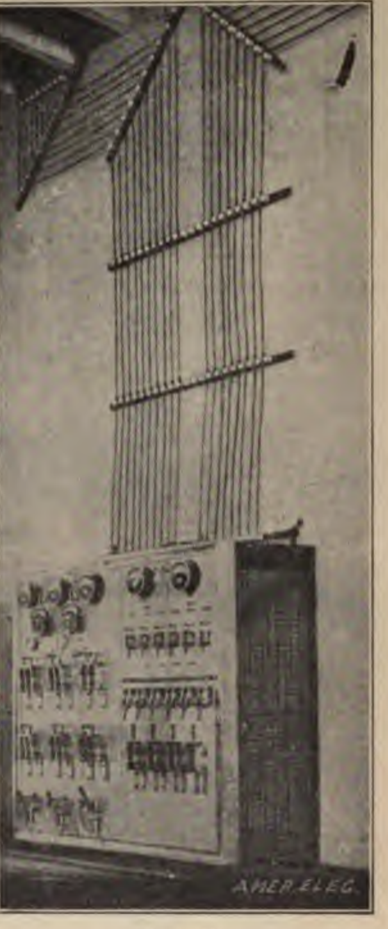


FIG. 18

MOLDING

Molding is principally used in making circuit extensions in completed buildings, although it is sometimes used for new work, where the use of cleat work would be objectionable from the standpoint of appearance, and where it would be impracticable, difficult, or expensive to install concealed wiring. Its principal use, however, is for extending circuits from existing outlets to new outlets in offices, stores, lofts, etc.

The rules of the National Electric Code covering the construction of wooden molding and the kind of wire required for molding work are as follows:

50. Wooden Moldings (Construction of).

(*For Wiring rule , see No. 24 l and m.*)

a. Must have, both outside and inside, at least two coats of waterproof material, or be impregnated with a moisture repellent.

b. Must be made in two pieces, a backing and a capping, and must afford suitable protection from abrasion. Must be so constructed as

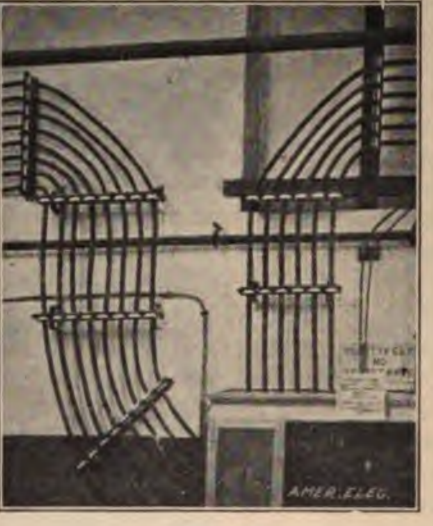


FIG. 19

to thoroughly encase the wire, be provided with a tongue not less than 1-2 inch in thickness between the conductors, and have exterior

FIG. 20

walls which under grooves shall not be less than 3-8 inch in thickness, and on the sides not less than 1-4 inch in thickness.

It is recommended that only hard-wood molding be used.

For Molding Work (Wires for).

l. Must have an *approved* rubber insulating covering. (See No. 41.)

m. Must never be placed in molding in concealed or damp places, or where the difference of potential between any two wires in the same molding is over 300 volts.

As a rule molding should not be placed directly against a brick wall, as the wall is likely to "sweat" and thus introduce moisture back of the molding.

Molding should never be used in any place where there is dampness, or where there is liable to be dampness at any time. For this reason, molding should not be used in cellars, or directly on brick walls, elevator shafts, laundries, etc. The rules forbid molding to be run concealed even for short distances, such as through partitions, walls, floors, etc.

Where the circuit work passes through floors, partitions, or walls, the conductors should be protected by means of porcelain tubes, or with lined (armored) iron conduit, or by plain iron pipe lined with flexible tubing. Where the porcelain tubes are liable to mechanical damage, they should be placed inside of iron pipes, as in the case of exposed wiring. In certain cases flexible tubes in iron pipes may be used to protect the conductor, but as a rule, the porcelain tube should always be used when possible.

Where porcelain tubes are used to protect the conductors where they pass through floors, the tube should be prolonged for at least a foot beyond the floor line; if lined iron pipe or plain pipe with flexible tubing be used, the pipe should be extended to the first outlet, or for a distance of at least five feet above the floor line. Where porcelain tubes are used to protect the passing through the floor, a "kicking block" or box, as shown in Fig. 21 should be installed to prevent the porcelain tubes from being broken.

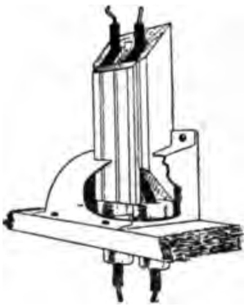


FIG. 21

Where wooden molding is run on walls, it should be protected for a height of at least five feet from the floor, by two parallel wooden strips projecting slightly beyond the molding, and placed at the sides of the same. These protecting strips can be dispensed with when the molding is run between door jams.

door trims, or in corners, or in other places where it would not be liable to mechanical injury.

A combination method of wiring, using molding in conjunction with flexible tubing, is frequently employed. In such cases, flexible tubing is utilized for the vertical portions of the circuit where such tubing can be readily installed, and molding used for the ceiling portions of the circuit where it might be difficult to conceal the wiring.

A better combination would be one in which molding was used in conjunction with rigid conduit, or with flexible steel conduit. In such cases, it is necessary to install an iron outlet box at the junction of the molding and metal conduit, an approved lock nut and bushing being installed at the end of the iron pipe. A combination of molding or flexible tubing, or conduit, is frequently employed in apartments, hotels, office buildings, etc., of non-fireproof construction, where wiring had not been orignally installed. In such cases, the molding may be run in a cornice in the hall; as it might be objectionable to have the work exposed in the room, "taps" could be made in the molding opposite to each room, and the circuit extensions from the molding to the center outlets in the room could be run concealed in flexible tubing or conduit, "fishing" the wires from the molding to the ceiling outlet. An illustration of this method is shown in Fig. 22.

As single-braided wire is allowed in molding, and as double-braided wire is required for the metal conduits, it would be necessary in all cases where a combination of moldings and rigid conduits were used, to use double-braided wire throughout, or else splice to double-braided wire at the junction box.

As stated in the rules, rubber-insulated conductors only are allowed for molding work, and weather-proof and slow-burning conductors should never be employed. As already stated, conductors for molding need only have a single outer braid over the rubber insulation.

The molding should be carefully selected, and should be free from knots and other defects, and of form, material, and design suitable for the place where it is to be used. If the molding is to be unpainted, it should be of Georgia pine, ash, or oak, unless appearance is of no importance. For ordinary cases, soft wood molding, such as white wood, spruce, etc., is generally used, and should be painted as required by the rules. While the

rules recommend the use of hard-wood molding, comparatively little hard-wood molding is used. Georgia pine, oak, or similar hard-wood moldings cost approximately twice as much as the soft-wood molding.

The use of wooden moldings in new buildings is not to be recommended for the reason that wooden molding is not usually

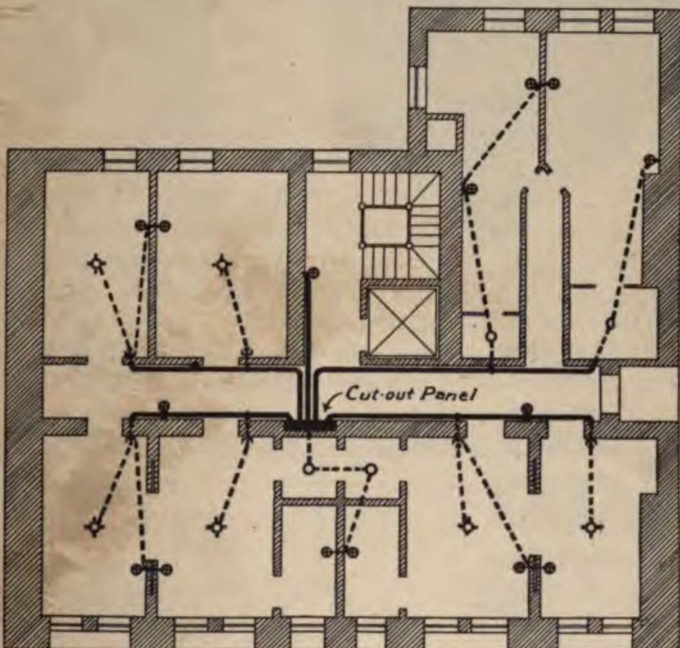


FIG. 22

fire-proof, and it would be better to run the conductors concealed in some form of conduit; if the circuit work were installed at the time the building were erected, it would cost but little more than molding, and would be much more substantial. In some cases, however, wooden molding might be provided in a new building on the ceiling as a means of affording facilities for making connections to outlets over desks, tables, etc., where it would be impossible to locate the outlet exactly before the building was plastered. In such cases, the molding could be installed on the ceiling at a distance of 18 to 24 inches from the walls, forming a rectangle on the ceiling. An approved form of rosette, such as

shown in Fig. 23 could then be installed at any point without disfiguring the ceiling.

As far as possible, circuits run in molding should be arranged symmetrically on the ceiling and walls, and should follow some general design or scheme, as indicated in Fig. 24. If necessary, blank or empty molding should be installed so as to complete the design. While this adds slightly to the cost, it greatly improves the appearance of the work. Of course, this method would not be followed in factories, or in other places where the appearance was of little or no importance.

Fig. 23

Figs. 25 to 26 show some new devices used for molding work. The various sizes of two and three-wire molding are shown

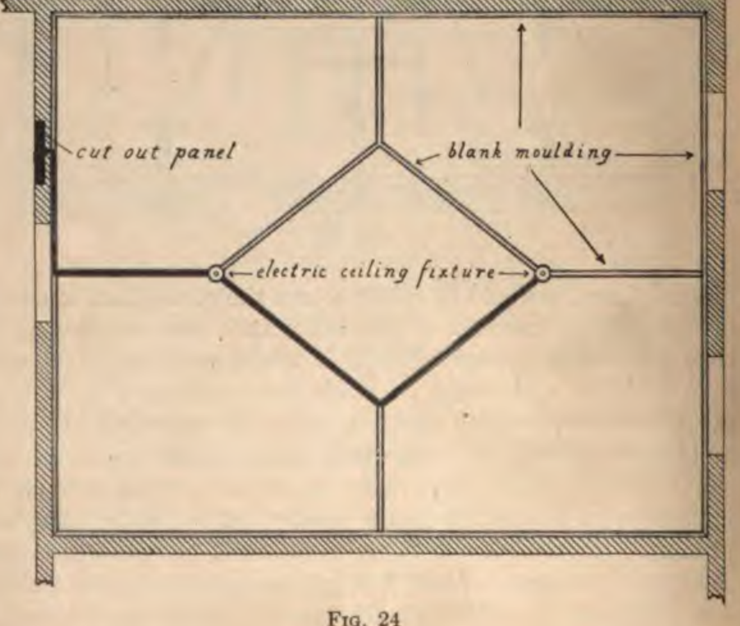


Fig. 24

in Figs. 27 and 28. These moldings are shown quarter the full size.

FIG. 25

FIG. 26

In private houses, and in certain cases, special molding should be provided to match the woodwork, ceilings, walls, etc., in the room, and should be specially designed to suit the condi-

FIG. 27

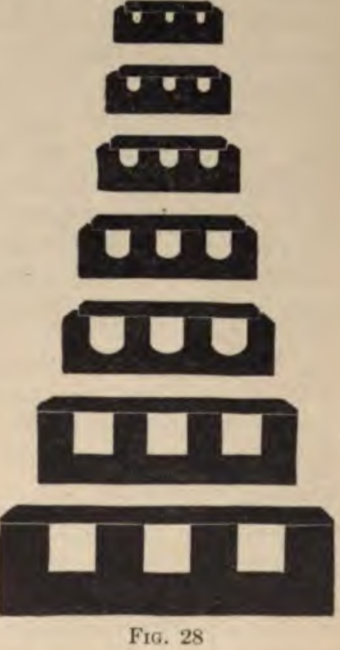


FIG. 28

tions. Molding with this special capping can be obtained, or it may be made to order

Where molding is secured to lath and plaster, the usual method is to bore small holes in the plaster and to use long, thin screws; this method is not to be recommended where a better and more substantial means of support can be obtained.

On brick walls, it is usual to drill the brick and to insert wooden plugs to which the molding is fastened. In terra-cotta arches, partitions, and in lathed partitions or ceilings, the molding should be secured by means of toggle joints. The molding should be fastened every 18 to 36 inches, depending upon the size of the molding, and for the very large sizes it should be fastened even more closely.

Relative Cost of Various Methods of Wiring

The relative costs of the various methods of wiring outlined in this chapter are given approximately herein below. The actual cost is not given in each case, for the reason that owing to variations in price of conduit, copper, and of labor, it would be practically impossible to give figures that would be of any value. As a rough guide, however, the figures given will be valuable in selecting a given method of wiring for a particular case, where the cost must be carefully considered.

The cost of circuit work run in conduit is taken as unity, as that is perhaps the most usual, and also the most expensive, method. The cost of the other methods of wiring are expressed in a percentagė or a fraction of unity.

The figures given include all labor and materials, and must be considered as approximate only, as they cover average conditions.

Method of Wiring	Relative Cost in per cent
Conduit Wiring	100
Molding (soft wood)	50
Molding (hard wood)	65
Molding (fire-proof wood)	80
Greenfield flexible conduit	80
Armored cable	70
Knob and tube wiring	35
Cleat work	40
Flexible tubing	40

CHAPTER III

CONDUCTORS

For interior wiring copper conductors have been used exclusively. Aluminum conductors would, of course, be out of the question owing to the increased cost in the rubber covering required; and where a conduit system was used the increased size of the conduit would be a fatal objection to aluminum or to any other material having a higher resistance than copper, owing to the increased size necessary to attain the same conductivity. The wires, therefore, should be of refined copper of the highest commercial conductivity (not less than 97 per cent), and should be properly tinned. The tinning process involves "pickling" the copper by running the conductors through a solution of acid to remove scale, rust, etc., so that the wire will be perfectly clean and bright; the conductors are then passed rapidly through a bath of molten tin and come out with a thin coat of bright tin. This tinning also makes it simpler and easier to make soldered joints and splices on the wire. For conductors up to sizes as large as No. 8 B. & S. gage, solid conductors may be used. For all conductors of sizes larger than No. 8 B. & S. gage, the necessary conductivity should be obtained by conductors made up of strands of smaller wires. (See table of wire equivalents, page 42.) The size of these strands should depend upon the size of the conductor and the conditions under which it is to be used. Where conductors are very large (as for example in the case of dynamo leads), and where it is essential that they should be as flexible as possible, strands as small as No. 20, or even 22, B. & S. gage may be used. Conductors for flexible cords, pendants, fixtures, etc., should also consist of very fine strands, so that they may be perfectly pliable and flexible. The individual strands for a No. 16 B. &. S. gage, flexible cord should be as fine as No. 30.

The maximum current allowed by the National Board of Fire Underwriters, to be carried by conductors of various sizes, is given in the table on page 43.

TABLE OF WIRE EQUIVALENTS.

To use the following Table, find in the vertical column at left the size of conductor desired; then follow along horizontally until the size of wire that is desired to use for the strands, and the corresponding number at top of column will give the number of strands of that size of wire required. The figures under irregular zig-zag line give the gage numbers of two conductors which will have the same conductivity as the corresponding conductor in left-hand column.

Number of Conductors

Gage Number* (B. & S.)	2	4	8	16	32	64	128	256	512	1024	2048	4096	8192	16384
0000	0	3	6	9	12	15	18	21	24	27	30	33	36	39
000	1	4	7	10	13	16	19	22	25	28	31	34	37	40
00	2	5	8	11	14	17	20	23	26	29	32	35	38	0+6
0	3	6	9	12	15	18	21	24	27	30	33	36	39	1+7
1	4	7	10	13	16	19	22	25	28	31	34	37	40	2+8
2	5	8	11	14	17	20	23	26	29	32	35	38	3+9	4+6
3	6	9	12	15	18	21	24	27	30	33	36	39	4+10	5+7
4	7	10	13	16	19	22	25	28	31	34	37	40	5+11	6+8
5	8	11	14	17	20	23	26	29	32	35	38	6+12	7+9	
6	9	12	15	18	21	24	27	30	33	36	39	7+13	8+10	
7	10	13	16	19	22	25	28	31	34	37	40	8+14	9+11	
8	11	14	17	20	23	26	29	32	35	38	9+15	10+12		
9	12	15	18	21	24	27	30	33	36	39	10+16	11+13		
10	13	16	19	22	25	28	31	34	37	40	11+17	12+14		
11	14	17	20	23	26	29	32	35	38	12+18	13+15			
12	15	18	21	24	27	30	33	36	39	13+19	14+16			
13	16	19	22	25	28	31	34	37	40	14+20	15+17			
14	17	20	23	26	29	32	35	38	15+21	16+18				
15	18	21	24	27	30	33	36	39	16+22	17+19				
16	19	22	25	28	31	34	37	40	17+23	18+20				
17	20	23	26	29	32	35	38	18+24	19+21					
18	21	24	27	30	33	36	39	19+25	20+22					
19	22	25	28	31	34	37	40	20+26	21+23					
20	23	26	29	32	35	38	21+27	22+24						
21	24	27	30	33	36	39	22+28	23+25						
22	25	28	31	34	37	40	23+29	24+26						
23	26	29	32	35	38	24+30	25+27							
24	27	30	33	36	39	25+31	26+28							
25	28	31	34	37	40	26+32	27+29							
26	29	32	35	38	27+33	28+30								
27	30	33	36	39	28+34	29+31								
28	31	34	37	40	29+35	30+32								
29	32	35	38	30+36	31+33									
30	33	36	39	31+37	32+34									
31	34	37	40	32+38	33+35									
32	35	38	33+39	34+36										
33	36	39	34+40	35+37										
34	37	40	36+39											
35	38	37+39												
36	39	38+40												
37	40													

	Table A. Rubber Insulation. See Rule No. 41.	Table B. Other Insulations. See Rule Nos. 42 to 44.	
B. & S. G.	Amperes.	Amperes.	Circular Mills.
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	211	312	211,600
Circular Mills.			
200,000	200	300	
300,000	270	400	
400,000	330	500	
500,000	390	590	
600,000	450	680	
700,000	500	760	
800,000	550	840	
900,000	600	920	
1,000,000	650	1,000	
1,100,000	690	1,080	
1,200,000	730	1,150	
1,300,000	770	1,220	
1,400,000	810	1,290	
1,500,000	850	1,360	
1,600,000	890	1,430	
1,700,000	930	1,490	
1,800,000	970	1,550	
1,900,000	1,010	1,610	
2,000,000	1,050	1,670	

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation.

For all interior wiring, conductors should have a covering which shall act both as an electrical insulator and as a mechanical

protection. In some cases, however, the covering may be such that its insulating qualities are of secondary consideration; in these cases, however, the insulation must be obtained by means of proper insulating supports. The various commercial forms of insulation now in use for conductors are as follows:

Rubber insulation with an outer protecting braid or tape; weather-proof insulation; Fire Underwriters' insulation; slow-burning, weather-proof insulation.

NUMBER, DIMENSIONS, LENGTH AND RESISTANCE OF PURE COPPER WIRE (SOLID)
(Copyright, 1897, by H. W. Fisher)

B & S. G. No.	Dia m	Area	Weight	Length		Resistance in International ohms at 68° F.	
	In Mils.	Circular Mils.	Lbs. per 1000 ft.	Feet per lb.	Feet per ohm.	Ohms per 1000 ft.	Ohms per lb.
	a	b	c	d	e	f	g
0000	460.	211600.	640.5	1.561	20440.	.04893	.00007639
000	409.6	167800.	508.0	1.969	16210.	.06170	.0001215
00	364.8	133100.	402.8	2.482	12850.	.07780	.0001931
0	324.9	105500.	319.5	3.130	10190.	.09811	.0003071
1	**289.3**	**83690.**	**253.3**	**3.947**	**8083.**	**.1237**	**.0004883**
2	257.6	66370.	200.9	4.977	6410.	.1560	.0007765
3	229.4	52630.	159.3	6.276	5084.	.1967	.001235
4	204.3	41740.	126.4	7.914	4031.	.2480	.001963
5	181.9	33100.	100.2	9.980	3197.	.3128	.003122
6	**162.0**	**26250.**	**79.46**	**12.58**	**2535.**	**.3944**	**.004963**
7	144.3	20820.	63.02	15.87	2011.	.4973	.007892
8	128.5	16510.	49.98	20.01	1595.	.6271	.01255
9	114.4	13090.	39.63	25.23	1265.	.7908	.01995
10	101.9	10380.	31.43	31.82	1003.	.9972	.03173
11	**90.74**	**8234.**	**24.93**	**40.12**	**795.3**	**1.257**	**.05045**
12	80.81	6530.	19.77	50.59	630.7	1.586	.08022
13	71.96	5178.	15.68	63.79	500.1	1.999	.1270
14	64.08	4107.	12.43	80.44	396.6	2.521	.2028
15	57.07	3257.	9.858	101.4	314.5	3.179	.3225
16	**50.82**	**2583.**	**7.818**	**127.9**	**249.4**	**4.009**	**.5128**
17	45.26	2048.	6.200	161.3	197.8	5.055	.8153

The data in the columns headed by the letters c, d, e, f, g, are based upon the report of the Committee on "Units and Standards" of the American Institute of Electrical Engineers, printed in the supplement of *Transactions*, October, 1893, as Dr. Matthiessen's correct standard. The weights of stranded conductors of a given resistance per 1000 feet vary with the number and size of wires used and the method of laying them up, hence no formulæ are given under any of the columns involving the weight, and the above figures are only approximate.

Rubber-Covered Conductors

Rubber-covered conductors should have, in addition to the rubber covering placed next to the conductor itself, an outer, protective covering of cotton braid; the outer covering to act merely as a mechanical protection.

The rubber covering ordinarily used for insulating conductors is not pure rubber, but consists (or, more correctly, should consist) of a compound containing from 20 to 35 per cent of pure rubber. The best India rubber (caoutchouc) is obtained from the Amazon Valley and is called Para. This Para gum, if used in the pure state, would be difficult to place on the conductor, would not be durable, and would deteriorate very rapidly, particularly at temperature above 120° F. For these reasons it is mixed with other materials, such as French chalk (talc), silicate of magnesia, sulphur, red lead, etc. The French chalk is the principal ingredient and makes the rubber easier to work. The sulphur is added for the purpose of vulcanizing the rubber. This process of vulcanization consists of raising the rubber compound to a temperature (about 240 to 280° F.) at which the sulphur melts and combines with the India rubber. The result of this combination makes the rubber stronger mechanically, and tends to prevent or retard decomposition which, under certain conditions, takes place at comparatively low temperature with unvulcanized rubber. The vulcanization is usually performed after the rubber and braid is placed on the conductors.

The India rubber used for making the rubber compound for insulating conductors should be pure Para gum, and not less than 20 per cent nor more than 40 per cent should be used in order to obtain a good compound. It is frequent practice to use "reclaimed," or old rubber, together with some pure gum for insulating conductors. This insulation is difficult to detect when new, but it deteriorates rapidly and loses its insulating qualities.

The advantages of rubber insulation for conductors are, that it is water-proof, flexible, fairly strong, and has high insulating qualities. Its disadvantages are that it does deteriorate more or less rapidly (depending upon the quality of compound used) and that it will not stand temperatures over 140° F. without rapid deterioration. All things considered, however, it is quite satisfactory (except in certain cases) for conductors for interior wiring. The practice among American manufacturers of rubber-

covered conductors for interior work differs on two points. Some manufacturers put two layers of rubber on the conductor, and others but one layer. In the former class the inside layer consists of a thin skin of non-vulcanized rubber, and is called a core. This layer is usually of very pure rubber and contains no sulphur or other material liable to injure the copper conductor. A coloring material is usually added to the mixture in order to designate the grade or make of wire. From this practice originate terms of "red core," "white core," etc., derived from the color of the inside rubber layer placed on the wire. Over this inside thin core is placed the second and principal insulating layer. The advantages claimed for this method of insulation are that it tends to prevent deterioration in the tinning of the wire, and that by placing the rubber on the conductor in two layers the probabilities of pin holes, or similar defects, in both layers at the same point, are considerably less than is the case with conductors insulated with but a single layer. The total thickness of rubber insulation is usually the same for the same grade of wire, whether the rubber is put on in a single layer or in two layers.

Where but one layer of rubber is used, it is sometimes put on in such a manner as to be seamless; in other cases it is laid over the conductor and has a seam on one side. In the former case the wire passes through a die, and the rubber, which is heated, is pressed in the hydraulic pressure around the conductor in such a manner as to form a homogeneous mass without seam or joint.

The following are specifications adopted by certain manufacturers, for a high-grade 30 per cent insulating compound for rubber-covered conductors:

Specifications for 30 per cent Rubber Insulating Compound for Wires and Cables

The compound shall contain not less than 30 per cent by weight of dry fine Para rubber, without any reclaimed or soft rubber. The composition of the remaining 70 per cent shall be left to the discretion of the manufacturer.

Chemical. — The vulcanized rubber compound shall contain not more than 5 per cent by weight of extractive matter.

Mechanical. — The rubber insulation shall be homogeneous in character, shall be placed concentrically about the conductor,

and shall have a tensile strength of not less than 800 pounds per square inch.

TABLE GIVING OUTSIDE DIAMETER OF RUBBER-COVERED CONDUCTORS BASED ON NATIONAL CODE REQUIREMENTS AS TO THICKNESS OF RUBBER AND BRAID

B. & S. G.	DIAMETER OVER ALL		
	Standard Strandings	Single Braid Inches.	Double Braid Inches
14	....	$\frac{13}{64}$	$\frac{17}{64}$
12	....	$\frac{14}{64}$	$\frac{18}{64}$
10	....	$\frac{15}{64}$	$\frac{19}{64}$
8	7-16	$\frac{21}{64}$	$\frac{25}{64}$
6	1-12x 8-16	$\frac{25}{64}$	$\frac{29}{64}$
5	1-12x 6-14	$\frac{26}{64}$	$\frac{30}{64}$
4	7-12	$\frac{28}{64}$	$\frac{32}{64}$
3	1-10x 6-12	$\frac{29}{64}$	$\frac{33}{64}$
2	1-11x 6-10	$\frac{32}{64}$	$\frac{36}{64}$
1	20-14	$\frac{37}{64}$	$\frac{41}{64}$
0	3-10x11-12	$\frac{38}{64}$	$\frac{42}{64}$
00	1-10x18-12	$\frac{42}{64}$	$\frac{46}{64}$
000	16-10	$\frac{45}{64}$	$\frac{50}{64}$
0000	19-12	$\frac{48}{64}$	$\frac{52}{64}$
Circular Mils			
250,000	30-11	$\frac{52}{64}$	$\frac{58}{64}$
300,000	36-11	$\frac{57}{64}$	$\frac{63}{64}$
350,000	33-10	$\frac{61}{64}$	$1\frac{3}{64}$
400,000	48-11	$\frac{63}{64}$	$1\frac{5}{64}$
450,000	54-11	$1\frac{2}{64}$	$1\frac{8}{64}$
500,000	60-11	$1\frac{5}{64}$	$1\frac{11}{64}$
600,000	72-11	$1\frac{12}{64}$	$1\frac{18}{64}$
700,000	84-11	$1\frac{18}{64}$	$1\frac{24}{64}$
750,000	91-11	$1\frac{19}{64}$	$1\frac{25}{64}$
800,000	48-8	$1\frac{21}{64}$	$1\frac{27}{64}$
900,000	30-8x22-10	$1\frac{24}{64}$	$1\frac{30}{64}$
1,000,000	61-8	$1\frac{30}{64}$	$1\frac{36}{64}$
1,100,000	66 No. 8	$1\frac{36}{64}$	$1\frac{40}{64}$
1,200,000	72 No. 8	$1\frac{38}{64}$	$1\frac{42}{64}$
1,300,000	79 No. 8	$1\frac{40}{64}$	$1\frac{44}{64}$
1,400,000	85 No. 8	$1\frac{44}{64}$	$1\frac{48}{64}$
1,500,000	91 No. 8	$1\frac{48}{64}$	$1\frac{52}{64}$
1,600,000	96 No. 8	$1\frac{50}{64}$	$1\frac{54}{64}$
1,700,000	161 No. 10	$1\frac{52}{64}$	$1\frac{56}{64}$
1,800,000	108 No. 8	$1\frac{56}{64}$	$1\frac{60}{64}$
1,900,000	179 No. 10	$1\frac{60}{64}$	2
2,000,000	61 No. 8 & 74 No. 9	2	$2\frac{4}{64}$

A sample of vulcanized rubber compound, not less than four inches in length, shall be cut from the wire, with a sharp knife held tangent to the copper. Marks shall be placed on the sample two inches apart. The sample shall be stretched until the marks

are six inches apart and then immediately released: one minute after such release, the marks shall not be over 2⅜ inches apart. The sample shall then be stretched four times its original length without rupture, and on release the marks shall not be over 2½ inches apart.

Electrical. — Each and every length of conductor shall comply with the requirements given in the following tables. The tests shall be made at the works of the manufacturer when the conductor is covered with vulcanized rubber, *and before the application of tape, braid, or other coverings.*

Tests shall be made after at least 36 hours' submersion in water and while still immersed. The insulation test shall follow the voltage test; shall be made with a battery of not less than 100 nor more than 500 volts, and the reading shall be taken after one minute's electrification.

Inspection. — The purchaser may send to the works of the manufacturer, a representative, who shall be afforded all necessary facilities to make the above specified electrical and mechanical tests, and, also, to assure himself that the 30 per cent of rubber above specified is actually put into the compound, but he shall not be privileged to inquire what ingredients are used to make up the remaining 70 per cent of the compound.

30 PER CENT RUBBER COMPOUND VOLTAGE TEST

SIZE	Thickness of Insulation in Inches											
	$\frac{3}{64}$	$\frac{2}{32}$	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{7}{64}$	$\frac{4}{32}$	$\frac{5}{32}$	$\frac{6}{32}$	$\frac{7}{32}$	$\frac{8}{32}$	$\frac{9}{32}$	$\frac{10}{32}$
1000000 to 550000	....	....	....	....	3000	4500	7500	10500	13500	16500	19500	22500
500000 to 250000	....	....	....	3000	4500	6000	9000	12000	15000	18000	21000	24000
$\frac{1}{0}$ to 1	....	....	3000	4500	6000	7500	10500	13500	16500	19500	22500	25500
2 to 7	....	3000	4500	6000	7500	9000	12000	15000	18000	21000	24000	27000
8 to 14	2250	3750	5250	6750	8250	9750	12750	15750	18750	....	....	....

NOTE: It is our experience that the above are sufficiently high voltages to employ. Higher voltages, although not necessarily causing a breakdown of the insulation, are apt to strain it.

Megohms per Mile — 60 Deg. F.
One Minute Electrification

	$\frac{3}{64}$	$\frac{2}{32}$	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{7}{64}$	$\frac{4}{32}$	$\frac{5}{32}$	$\frac{6}{32}$	$\frac{7}{32}$
1000000 C. M.	....	....	....	....	530	600	730	855	975
900000 "	....	....	....	....	555	625	760	900	1025
800000 "	....	....	....	....	585	650	800	950	1075
700000 "	....	....	....	....	620	700	850	1000	1150
600000 "	....	....	....	....	675	750	900	1075	1200
500000 "	....	....	....	625	720	800	975	1150	1300
400000 "	....	....	....	700	800	900	1100	1250	1400
300000 "	....	....	....	800	900	1000	1200	1400	1600
250000 "	....	....	....	850	960	1100	1300	1500	1700
4/0 Strd.	....	....	800	950	1050	1175	1400	1600	1800
3/0 "	....	....	850	1050	1150	1300	1500	1800	2000
2/0 "	....	....	950	1150	1275	1400	1700	1900	2150
1/0 "	....	....	1050	1250	1400	1550	1800	2100	2350
1 Solid	....	....	1300	1500	1700	1900	2200	2500	2800
2 "	....	1200	1400	1600	1850	2050	2400	2700	3000
3 "	....	1300	1500	1800	2000	2200	2600	2950	3250
4 "	....	1400	1700	2000	2200	2400	2800	3150	3450
5 "	....	1550	1850	2150	2400	2600	3000	3400	3700
6 "	....	1700	2000	2300	2600	2800	3250	3600	3975
8 "	1600	2000	2400	2700	3000	3300	3750	4150	4500
9 "	1800	2200	2600	2900	3250	3500	4000	4400	4790
10 "	2000	2400	2800	3250	3500	3750	4250	4700	5050
12 "	2300	2800	3200	3600	3950	4250	4800	5250	5600
14 "	2700	3250	3700	4100	4500	4800	5350	5850	6250

NOTE: The above are conservative figures, and no compound containing 30 per cent of dry fine Para rubber should give lower results.

Weather-proof Insulation

Weather-proof insulation consists of two or more layers of cotton, impregnated with a moisture-resisting compound containing asphaltum, or some other similar material. This insulation is the same as that used for outside conductors for overhead line-work. Its advantages are, that it is cheap, very durable, and does not deteriorate (unless subject to high temperatures, which are apt to melt the compound). Its disadvantages are, that it is more or less inflammable and has not high insulating qualities.

For the reason that this insulation is inflammable, care should be taken in the use of conductors covered with it at points where any considerable number of the conductors are brought together; or where there is much woodwork or other combustible material. It is particularly adapted for use in tunnels, in the cellar of fire-proof buildings, etc. It is also particularly adapted for use in breweries, for open sheds and buildings, and in places more or less subject to moisture or dampness. This insulation should

rather be called covering, as it is more in the nature of a mechanical protection to the wire and prevents short circuits and grounds, which might occur if a bare copper wire were used. It is needless to say that the conductors having this type of insulation should never be used in conduits, nor, in fact, in any other way except exposed, on porcelain or glass insulators. Care should be taken throughout that the conductors are carefully isolated from other conductors, pipes, or any conducting material.

Conductors having weather-proof, slow-burning, and underwriters' insulation are usually sold by the pound, including the conductor covering. The market price of conductors having weather-proof insulation usually varies (when purchased in large quantities) from fifteen to twenty-eight cents a pound, depending upon the market price of copper.

The rules of the National Board of Fire Underwriters governing this class of insulation are given in rule 44 of the National Electric Code, as follows:

44. Weather-proof Wire.

a. The insulating covering shall consist of at least three braids, all of which must be thoroughly saturated with a dense moisture-proof compound, applied in such a manner as to drive any atmospheric moisture from the cotton braiding, thereby securing a covering to a great degree water-proof and of high insulating power. This compound must retain its elasticity at 0 degrees Fahrenheit and must not drip at 160 degrees Fahrenheit. The thickness of insulation must not be less than that required for "slow-burning weather-proof wire," and the outer surface must be thoroughly slicked down.

This wire is for use out-doors, where moisture is certain and where fire-proof qualities are not neeessary.

SLOW BURNING OR FIRE UNDERWRITERS' INSULATION

This insulation consists of cotton braid treated with a fire-resisting compound containing white lead, or a cheaper substitute containing oxide of zinc and chalk. The advantages of this type of insulation are, cheapness, durability, and incombustibility. Its disadvantages are, that it absorbs moisture somewhat readily, particularly if inferior materials are substituted for the white lead in the insulating compound, and it has not high insulating qualities. It should be installed in the same manner that the weather-proof conductors are installed, viz., exposed on porcelain or glass insulators. Unlike weather-proof insulation, however,

TABLE OF DOUBLE AND TRIPLE COVERED WEATHER-PROOF WIRE AND CABLE

SOLID CONDUCTORS

Size B. & S. Gage	Pounds per 1000 Feet	
	Double Covered	Triple Covered
No. 14	20	25
12	30	35
10	46	53
9	54	62
8	66	75
6	100	112
5	122	135
4	151	164
3	185	199
2	239	260
1	294	316
0	377	407
00	467	502
000	587	629
0000	723	767

STRANDED CONDUCTORS

Size B. & S. Gage	Pounds per 1000 Feet	
	Double Covered	Triple Covered
No. 8	68	78
6	103	115
5	126	140
4	155	170
3	190	206
2	246	270
1	303	328
0	388	424
00	482	522
000	604	653
0000	745	800
C.M.		
250,000	907	985
300,000	1083	1174
350,000	1248	1345
400,000	1436	1553
450,000	1601	1724
500,000	1765	1894
600,000	2093	2235
700,000	2471	2650
750,000	2635	2822
800,000	2799	2992
900,000	3127	3322
1,000,000	3456	3674
1,500,000	5098	5380
2,000,000	6690	7008

it should not be installed in damp or moist places on account of its hygroscopic qualities. While both the weather-proof and underwriters' insulation depend upon the insulator supporting the cables and not upon the insulation on the conductors themselves for the insulation of a system; nevertheless, it would be unwise to install underwriters' insulation in very damp places because of the liability of wires, boards, etc., accidentally getting across the conductors and thereby causing leakage. As a matter of fact it should only be used after consulting the local inspection authorities. For dry temperatures of 130 degrees and upwards, it would be advisable to use conductors having this kind of insulation as it does not deteriorate at ordinarily high temperatures, such as would entirely destroy rubber insulation and which would soften weather-proof insulation.

The rules and recommendations of the National Board of Fire Underwriters, governing this class of insulation, are given under Rule 43 of the National Electric Code as follows:—

43. Slow-burning Wire.

a. The insulation must consist of layers of cotton or other thread, all the interstices of which must be filled with the fire-proofing compound, or of material having equivalent fire-resisting and insulating properties. The outer layer must be braided and specially designed to withstand abrasion. The thickness of insulation must not be less than that required for "Slow-Burning Weather-proof Wire," and the outer surface must be finished smooth and hard.

The solid constituent of the fire-proofing compound must not be susceptible to moisture, and must not burn even when ground in an oxidizable oil, making a compound which, while proof against fire and moisture, at the same time has considerable elasticity, and which when dry will suffer no change at a temperature of 250 degrees Fahrenheit, and which will not burn at even a higher temperature.

"Slow-burning wire" must not be used without special permission from the Inspection Department having jurisdiction.

This is practically the old so-called "underwriters'" insulation. It is especially useful in hot, dry places where ordinary insulations would perish, and where wires are bunched, as on the back of a large switchboard or in a wire tower, so that the accumulation of rubber or weather-proof insulations would result in an objectionable large mass of highly inflammable material. Its use is restricted, as its insulating qualities are not high and are diminished by moisture.

The weights of the slow-burning wire are approximately the same as the weights of triple-braided weather-proof conductor given herein above.

SLOW-BURNING WEATHER-PROOF

This type of insulation consists of a combination of the Weather-proof and Underwriters' Insulation. In all cases the layer of Underwriters' must be on the outside with an inside layer of weather-proof insulation. The fire-proof coating comprises about six tenths of the total covering. Where the fire-proof coating is on the outside the wire is known as weather-proof slow-burning, and vice versa. This type of insulation is used where the conductors are to be run exposed and where moisture-resisting qualities are wanted, and where at the same time it is wished to avoid an excess of inflammable covering on the conductors. These conductors should also be set exposed on porcelain or glass insulators in all cases.

The rules and recommendations of the National Board of Fire Underwriters, as modified in December, 1905, governing conductors having this class of insulation, are given in rule No. 42 of the National Electric Code, as follows: —

42. Slow-burning Weather-proof.

The wire is not as burnable as "weather-proof," nor as subject to softening under heat. It is not suitable for outside work.

a. The insulation shall consist of two coatings, one to be fire-proof in character, the other to be weather-proof. The fire-proof coating must be on the outside and must comprise about six tenths of the total thickness of the wall. The completed covering must be of a thickness not less than that given in the following table for B. & S. gage sizes:

From	14 to	8,	inclusive,	$\frac{3}{64}''$
From	7 to	2,	inclusive,	$\frac{1}{16}''$
From	2 to	0000,	inclusive,	$\frac{5}{64}''$
From	0000 to	500,000,	c. m.	$\frac{3}{32}''$
From	500,000 to	1,000,000,	c. m.	$\frac{7}{64}''$
Larger than		1,000,000,	c. m.	$\frac{1}{8}''$

Measurements of insulating wall are to be made at the thinnest portion of the dielectric.

This wire is not as burnable as "weather-proof," nor as subject to softening under heat. It is not suitable for outside work.

b. The fire-proof coating shall be of the same kind as that required for "slow-burning wire," and must be finished with a hard, smooth surface.

c. The weather-proof coating shall consist of a stout braid, applied and treated as required for "weather-proof wire."

The weights of various sizes of slow-burning weather-proof wire are given in the following table: —

TABLE OF SLOW-BURNING WEATHER-PROOF SOLID WIRE

B. & S. Gage	Weight per 1000 ft. lbs.
No. 14	30
12	42
10	60
8	85
6	127
5	155
4	190
3	230
2	280
1	340
0	462
00	562
000	710
0000	862

The weight of weather-proof slow-burning solid wire (having the weather-proof insulation inside) is about 5 per cent heavier than the weights in the above table.

CHAPTER IV

FUSES AND SAFETY DEVICES

EVEN in the earliest stages of electric wiring it was evident that some means must be provided for protecting electric conductors, appliances, and machinery from excessive currents and overloads. For this purpose short lengths of metal conductors having a low fusing point were placed in circuit with the conductor, and were so designed that a slight increase in current above the normal amount would melt the fuse and open the circuit.

As lead, tin, or some alloy of these metals was found to answer this purpose admirably, owing to their low fusing point, they were adopted for this purpose and have continued in general use up to the present time, although zinc and aluminum are now used to a certain extent; copper and platinum are also used in certain cases, the former for very heavy currents and the latter for very light currents.

Until recently comparatively little attention has been given to fuses and their manufacture, but in the last four or five years material advance has been made both in their manufacture and their use. As already stated the earliest form of fuse consisted of short lengths of fuse wires; they were soon replaced by the Edison fuse plug, which was devised by Edison in the early eighties. This device had many important advantages, as it was interchangeable, it could be safely and quickly installed and easily replaced, and, being enclosed, it was safer. Although this fuse was first brought out over twenty years ago, it still continues in use in practically its original form, although the original wooden plug was replaced later by a glass plug, and still later by a porcelain plug; indeed it is unquestionably used to a greater extent to-day than any other type of fuse. It is not particularly accurate or reliable, however, owing to its extremely short length; it is fairly high in first cost, and neither adapted nor allowed for potentials over 125 volts, except on Edison three-wire systems with grounded neutral. It is also limited in capacity to about 60 amperes, being impracticable for large currents.

Sometime after the introduction of the Edison fuse plug, open link fuses were made up with copper terminals, which was a considerable improvement over the fuse wire without terminals. These open fuses had the advantages of low first cost and of being readily detected when disrupted or blown.

The disadvantages of the open-type fuses are the violence of their disruption when short-circuited, or even if ordinarily overloaded, the danger of fire, of personal injury, and the disfigurement of the cut-out block or panel.

Numerous other types of uses were brought out at various times, which were protected in various ways, some having rubber tubing over the fuse wire, others being placed on or between blocks of porcelain or similar material. None of these fuses were used to any great extent, however.

About 1895 a form of fuse and holder was introduced which was used to a considerable extent and was generally known as the removable fuse holder cut-out. This device consisted of a block of porcelain to which were secured knife blades at each end which would fit into corresponding clips on the panel-board. The two fuses corresponding to the two legs of the circuit were inserted between screw contacts, forming extensions of the knife blades, the two fuses being usually separated by a ridge or bar molded on the porcelain block.

These fuses were used to a very considerable extent and had the advantage of being easily removed and the fuse quickly replaced at a very low cost. A small stock of these fuse holders could be kept on hand and, when a fuse blew, the holder could be removed and at once replaced by another holder already fused. The fuse could then be replaced in the first fuse holder at any leisure moment.

These fuse holders, however, were difficult to make so as to secure perfect alignment with the knife contacts on the panel-boards. They were also expensive, the porcelain holders were easily broken, and, being special were difficult to replace. They are not now approved by the National Board of Fire Underwriters.

As already stated, all the various types of fuses have been more or less unreliable and inaccurate. These defects have been due to variations in the alloy, defective and improper manufacture and rating, without due allowance for the length of fuse and for the size and form of the fuse terminals. All three of these

factors (length of fuse and the form and size of terminal) play a very important part in the behavior of a fuse and should be the subject of careful consideration and accurate calculation. These matters are now given much more attention than formerly, with the result that considerable improvement has been made in all these respects.

The greatest recent advance, however, in the manufacture of fuses has been the introduction of the so-called cartridge fuse. When the 220-volt lamp was put on the market and began to be used, great trouble was found in obtaining satisfactory fuses for protecting the branch circuits and mains. Both the Edison fuse plug and the open-link fuse would "arc" and disrupt violently at this voltage, and the open fuse would frequently blow the adjacent fuses.

The cartridge fuse consists of a fuse centrally placed in a tube of vulcanized fiber, paper, or similar material, having the fuse terminals connected with suitable contact pieces to the ends of the tubes. The tubes are either wholly or partly filled with a peculiar light porous material which in some cases closely resembles chalk and in other cases appears to be a mixture of a chalk with soapstone and other substances.

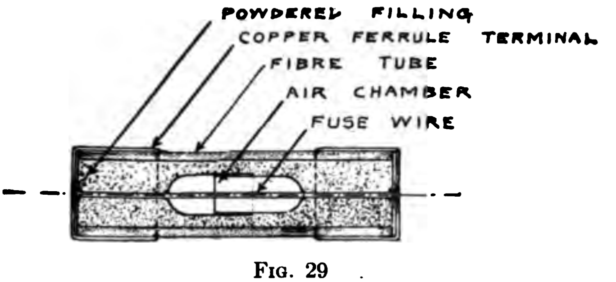


FIG. 29

When a fuse of this type is blown by a short circuit or overload current, the formation and maintenance of an arc is prevented. This preventive action is usually mechanical, but with some kinds of filling material a chemical action takes place between the melted fuse and the filling; in other cases the fuse blows in a small air chamber. (See Fig. 29.)

It is unquestionably true that an arc is prevented by the cartridge fuse and that this type is far more accurate and blows more nearly at the proper point than other type of fuse. Other

advantages of the enclosed fuse are that it is easily manipulated, is well adapted for potentials up to and including 500 volts, it is not subject to such variable factors as drafts or air currents, or from contact with bodies which are good conductors of heat. Its disadvantages are: It is somewhat expensive as compared to other forms of fuses; it is not suitable for heavy currents; and it is difficult to locate blown fuses. Another disadvantage is that in some cases enclosed fuses blow *too* soon. Until recently great difficulty was experienced with these fuses, owing to the great variety of lengths and forms of terminals, but they are now standardized.

Several attempts have been made to provide means for locating blown cartridge fuses by the use of visible indicators. Two forms of these have been used to a considerable extent but with no very great degree of success. The first form consisted of a secondary high resistance wire of very small diameter and low fusing point, placed on the outside of the fuse tube and connected in multiple with the fuse proper inside the tube. When the fuse blew, the outside wire, of course, immediately melted and gave evidence that the inside fuse had blown. The trouble with this device was that the indicator was frequently broken by careless handling before the fuse had been blown or before it had been used. The second device is called the bull's-eye indicator and is similar to the first inasmuch as a small wire is used in multiple with the fuse, but with the difference that in this case the wire is placed inside the tube and passes a small opening, which is covered by a piece of paper having a circle or bull's-eye over the small hole. When the fuse blows the wire melts and punctures the paper, showing a black dot inside of the circle. The principal trouble with this device is that it doesn't always work as intended, perhaps largely due to defective manufacture. Then it is also difficult to see the indicating device quickly and readily on a panel-board containing a number of fuses. The safest and surest way to determine blown fuses is to use a testing lamp across the outside terminals of a pair of fuses when connected in a circuit. In this way a blown fuse can quickly and easily be located.

In regard to the capacities of cartridge fuses, while they have been made up for capacities of 500 amperes, they are really not (at present) desirable for sizes over 300 amperes, owing to their relatively high cost, violence of disruption, difficulties of obtaining

proper terminals, awkwardness of design, and rigidity. For ordinary (low) voltages the writer advises the use of cartridge fuses up to and including 25 amperes, but open fuses above that capacity.

The relative approximate cost of the various kinds of fuses for small currents (up to 25 amperes) at present, in large quantities, are given below.

Open-link fuse with copper terminals, three-quarters of a cent each; Edison fuse plug, five cents each; Edison fuse plug with cartridge fuse complete, fifteen cents each; cartridge fuse, eight cents each.

These prices are, of course, subject to considerable fluctuation and are only given to show the approximate relative cost of the various kinds of fuses.

The rules of the National Board of Fire Underwriters governing the use of fuses have undergone considerable change in the last few years, and for that reason it is deemed best to reproduce here some of the rules governing the installation, construction, and kind of fuses allowed.

Considerable improvement is still needed in the design and manufacture of fuses of large ampere capacity. A great deal of trouble is caused by the unreliability of fuses of 1000 amperes and upward. This is a very important problem, as the premature disruption of large fuses causes great annoyance and inconvenience, and often considerable loss of time and money. Copper fuses are frequently used for capacities of 1000 amperes and above, but fuses made of this metal are objectionable, owing to the high temperature at which they fuse. Even at 25 per cent below their fusing point, they are often so hot that they heat the contact switches to which they are connected. In many cases, however, the copper fuses are preferable for large sizes. Table on page 60 gives data relating to copper fuses which has never been published before, so far as the writer knows.

53. Fuses. (Construction of)

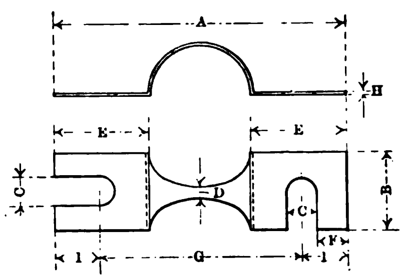
Link Fuses

a. Terminals. — Must have contact surfaces or tips of harder metal, having perfect electrical connections with the fusible part of the strip.

The use of the hard metal tip is to afford a strong mechanical bearing for the screws, clamps, or other devices provided for holding the fuse.

Data on Dimensions of Copper Fuses

Amperes	A	B	C	D	E	F	G	I	H
25	$1\frac{15}{16}$	$\frac{7}{16}$	$\frac{3}{16}$	$\frac{1}{16}$	$\frac{17}{32}$	$\frac{1}{8}$	$1\frac{1}{2}$	$\frac{7}{32}$	.0071
50	$2\frac{1}{4}$	$\frac{5}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{11}{16}$	$\frac{3}{16}$	$1\frac{5}{8}$	$\frac{5}{16}$	.0071
75	$2\frac{5}{8}$	$\frac{3}{4}$	$\frac{5}{16}$	$\frac{3}{32}$	$\frac{7}{8}$	$\frac{7}{32}$	$1\frac{7}{8}$	$\frac{3}{8}$	.0126
100	$3\frac{1}{8}$	$\frac{7}{8}$	$\frac{5}{16}$	$\frac{1}{8}$	1	$\frac{9}{32}$	$2\frac{1}{4}$	$\frac{7}{16}$	.0126
150	$4\frac{1}{8}$	1	$\frac{3}{8}$	$\frac{3}{16}$	$1\frac{1}{8}$	$\frac{5}{16}$	$3\frac{1}{8}$	$\frac{1}{2}$	.0126
200	$4\frac{1}{4}$	1	$\frac{7}{16}$	$\frac{1}{8}$	$1\frac{3}{16}$	$\frac{9}{32}$	$3\frac{1}{4}$	$\frac{1}{2}$	.025
250	$4\frac{1}{4}$	1	$\frac{7}{16}$	$\frac{5}{32}$	$1\frac{3}{16}$	$\frac{9}{32}$	$3\frac{1}{4}$	$\frac{1}{2}$	.025
300	$4\frac{5}{8}$	$1\frac{1}{8}$	$\frac{7}{16}$	$\frac{7}{32}$	$1\frac{3}{8}$	$\frac{11}{32}$	$3\frac{1}{2}$	$\frac{9}{16}$	.025
350	$4\frac{5}{8}$	$1\frac{1}{8}$	$\frac{7}{16}$	$\frac{1}{4}$	$1\frac{3}{8}$	$\frac{11}{32}$	$3\frac{1}{2}$	$\frac{9}{16}$	.025
400	$4\frac{3}{4}$	$1\frac{1}{4}$	$\frac{1}{2}$	$\frac{9}{32}$	$1\frac{7}{16}$	$\frac{3}{8}$	$3\frac{1}{2}$	$\frac{5}{8}$	.025
450	$4\frac{3}{4}$	$1\frac{1}{4}$	$\frac{1}{2}$	$\frac{5}{16}$	$1\frac{7}{16}$	$\frac{3}{8}$	$3\frac{1}{2}$	$\frac{5}{8}$	.025
500	$5\frac{1}{8}$	$1\frac{3}{8}$	$\frac{1}{2}$	$\frac{11}{32}$	$1\frac{5}{8}$	$\frac{7}{16}$	$3\frac{3}{4}$	$\frac{11}{16}$	.025
600	$5\frac{1}{4}$	$1\frac{1}{2}$	$\frac{9}{16}$	$\frac{3}{16}$	$1\frac{11}{16}$	$\frac{15}{32}$	$3\frac{3}{4}$	$\frac{3}{4}$	.051
700	$5\frac{1}{4}$	$1\frac{1}{2}$	$\frac{9}{16}$	$\frac{7}{32}$	$1\frac{11}{16}$	$\frac{15}{32}$	$3\frac{3}{4}$	$\frac{3}{4}$	.051
800	$5\frac{1}{2}$	$1\frac{3}{4}$	$\frac{9}{16}$	$\frac{1}{4}$	$1\frac{13}{16}$	$\frac{19}{32}$	$3\frac{3}{4}$	$\frac{7}{8}$	.051
900	$5\frac{1}{2}$	$1\frac{3}{4}$	$\frac{9}{16}$	$\frac{5}{16}$	$1\frac{13}{16}$	$\frac{19}{32}$	$3\frac{3}{4}$	$\frac{7}{8}$	.051
1000	$5\frac{1}{2}$	$1\frac{3}{4}$	$\frac{9}{16}$	$\frac{11}{32}$	$1\frac{13}{16}$	$\frac{19}{32}$	$3\frac{3}{4}$	$\frac{7}{8}$	.051
1100	$6\frac{1}{2}$	$2\frac{1}{4}$	$\frac{9}{16}$	$\frac{3}{8}$	$2\frac{5}{16}$	$\frac{25}{32}$	$4\frac{1}{4}$	$1\frac{1}{8}$	.051
1200	$6\frac{1}{2}$	$2\frac{1}{4}$	$\frac{9}{16}$	$\frac{13}{32}$	$2\frac{5}{16}$	$\frac{27}{32}$	$4\frac{1}{4}$	$1\frac{1}{8}$	.051
1500	$7\frac{1}{2}$	$2\frac{3}{4}$	$\frac{9}{16}$	$\frac{1}{2}$	$2\frac{13}{16}$	$1\frac{3}{32}$	$4\frac{3}{4}$	$1\frac{3}{8}$	.051



b. Rating. — Must be stamped with about 80 per cent of the maximum current which they can carry indefinitely, thus allowing about 25 per cent overload before the fuse melts.

With naked open fuses, of ordinary shapes and with not over 500 amperes capacity, the *minimum* current which will melt them in about five minutes may be safely taken as the melting point, as the fuse practically reaches its maximum temperature in this time. With larger fuses a longer time is necessary. This data is given to facilitate testing.

c. Marking. — Fuse terminals must be stamped with the maker's name or initials, or with some known trade-mark.

Enclosed Fuses, — Plug and Cartridge Type

These requirements do not apply to fuses for rosettes, attachment plugs, car lighting, cut-outs and protective devices for signaling systems.

d. Construction. — The fuse plug or cartridge must be sufficiently dust-tight so that lint and dust cannot collect around the fusible wire and become ignited when the fuse is blown.

The fusible wire must be attached to the plug or cartridge terminals in such a way as to secure a thoroughly good connection and to make it difficult for it to be replaced when melted.

e. Classification. — Must be classified to correspond with the different classes of cut-out blocks, and must be so designed that it will be impossible to put any fuse of a given class into a cut-out block which is designed for a current or voltage lower than that of the class to which the fuse belongs.

f. Terminals. — The fuse terminals must be sufficiently heavy to ensure mechanical strength and rigidity. The styles of terminals must be as follows:

0–250 Volts.

0–30 “	*A* Cartridge fuse (ferrule contact) to fit	*a*, spring clip terminals. *b*, Edison plug casings.
	B Approved plugs for Edison cut-outs.	
31–60 “	Cartridge fuse (ferrule contact) to fit	*a*, spring clip terminals. *b*, Edison plug casings.
61–100 “ 101–200 “ 201–400 “ 401–600 “	Cartridge fuse (knife blade contact).	

251–600 Volts.

0–30 amps. 31–60 “	Cartridge fuse (ferrule contact).
61–100 “ 101–200 “ 201–400 “	Cartridge fuse (knife blade contact).

g. Dimensions. — Cartridge-enclosed fuses and corresponding cut-out blocks must conform to the dimensions given in the table attached.

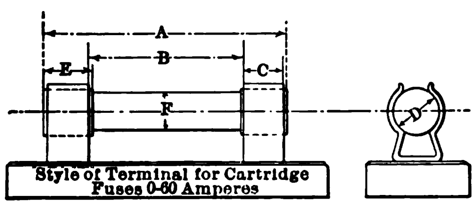


Fig. 30

Voltage.	Rated Capacity. Amperes.		A Length over Terminals. Inches.	B Distance between Contact Clips. Inches.	C Width of Contact Clips. Inches.
0–250	0–30	Form 1	2	1	$\frac{1}{2}$
	31–60		3	$1\frac{3}{4}$	$\frac{5}{8}$
	61–100	Form 2	$5\frac{7}{8}$	4	$\frac{7}{8}$
	101–200		$7\frac{1}{8}$	$4\frac{1}{2}$	$1\frac{1}{4}$
	201–400		$8\frac{5}{8}$	5	$1\frac{5}{8}$
	401–600		$10\frac{3}{8}$	6	$2\frac{1}{8}$
251–600	0–30	Form 1	5	4	$\frac{1}{2}$
	31–60		$5\frac{1}{2}$	$4\frac{1}{4}$	$\frac{5}{8}$
	61–100	Form 2	$7\frac{7}{8}$	6	$\frac{7}{8}$
	101–200		$9\frac{5}{8}$	7	$1\frac{1}{4}$
	201–400		$11\frac{5}{8}$	8	$1\frac{3}{4}$

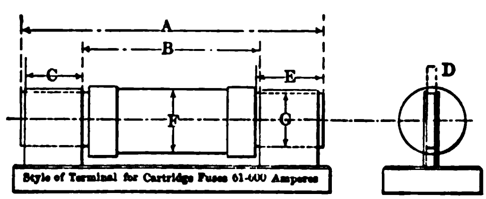


FIG. 31

D	E	F	G	
Diameter of Ferrules or Thickness of Terminal Blades. Inches.	Min. Length of Ferrules or of Terminal Blades outside of Tube. .Inches.	Dia. of Tube. Inches.	Width of Terminal Blades. Inches.	Rated Capacity Amperes.
$\frac{9}{16}$ $\frac{13}{16}$	$\frac{1}{2}$ $\frac{5}{8}$	$\frac{1}{2}$ $\frac{3}{4}$	Form 1	0–30 '31–60
$\frac{1}{8}$ $\frac{3}{16}$ $\frac{1}{4}$ $\frac{1}{4}$	1 $1\frac{3}{8}$ $1\frac{7}{8}$ $2\frac{1}{4}$	1 $1\frac{1}{2}$ 2 $2\frac{1}{2}$	$\frac{3}{4}$ $1\frac{1}{4}$ $1\frac{5}{8}$ 2 Form 2	61–100 101–200 201–400 401–600
$\frac{13}{16}$ $1\frac{1}{16}$	$\frac{1}{2}$ $\frac{5}{8}$	$\frac{3}{4}$ 1	Form 1	0–30 31–60
$\frac{1}{8}$ $\frac{3}{16}$ $\frac{1}{4}$	1 $1\frac{3}{8}$ $1\frac{7}{8}$	$1\frac{1}{4}$ $1\frac{3}{4}$ $2\frac{1}{2}$	$\frac{3}{4}$ $1\frac{1}{4}$ $1\frac{5}{8}$ Form 2	61–100 101–200 201–400

h. RATING. — Fuses must be so constructed that with the surrounding atmosphere at a temperature of 75 degrees Fahrenheit they will carry indefinitely a current 10 per cent greater than that at which they are rated, and at a current 25 per cent greater than the rating they will open the circuit without reaching a temperature which will injure the fuse tube or terminals of the fuse block. With a current 50 per cent greater than the rating and at room temperature of 75 degrees Fahrenheit, the fuses, starting cold, must blow within the time specified.

0– 30 amperes,	30 seconds.
31– 60 "	1 minute.
61–100 "	2 minutes.
101–200 "	4 "
201–400 "	8 "
401–600 "	10 "

i. MARKING. — Must be marked, where it will be plainly visible, with the name or trade-mark of the maker, the voltage and current for which the fuse is designed, and the words "National Electric Code Standard." Each fuse must have a label, the color of which must be green for 250-volt fuses and red for 600-volt fuses.

It will be satisfactory to abbreviate the above designation to "N. E. Code St'd" where space is necessarily limited.

j. TEMPERATURE RISE. — The temperature of the exterior of the

fuse enclosure must not rise more than 125 degrees Fahrenheit above that of the surrounding air when the fuse is carrying the current for which it is rated.

k. Test. — Must not hold an arc or throw out melted metal or sufficient flame to ignite easily inflammable material on or near the cut-out, when only one fuse is blown at a time on a short-circuit, on a system having a capacity of 300 kw. or over, at the voltage for which the fuse is rated.

Table gives the fusing current of commercial fuse wire.

Melting Points of Commercial Fuse Wire
Table by Mr. Bathurst.

Fusing Current Amperes	Diameter in Thousandths of an Inch	Nearest B. & S. Gage
1.730	.010	30
4.892	.020	24
8.988	.030	20
11.32	.035	19
13.34	.040	18
19.84	.050	16
25.42	.060	14
32.04	.070	13
39.14	.080	12
54.10	.100	10
63.11	.110	9
81.08	.130	8
90.61	.140	7
100.50	.150	6½
110.70	.160	6
132.10	.180	5
154.70	.200	4

Of course the above figures are approximate only, as the fusing point depends on the proportion and kind of alloys used, kind and form of terminal, length of fuse, etc., etc.

Table gives various data relating to fusing currents of different materials.

STRENGTH. $d=\left(\frac{i}{a}\right)^{\frac{2}{3}}$ i = CURRENT, a = CONSTANT, AND d = DIAMETER.

Derived from Tables of W. H. PREECE.

Current in Amperes	Copper, a = 10,244 Diameter in Inches	Copper Nearest B. & S. Gage	Aluminum, a = 7,585 Diameter in Inches	Aluminum Nearest B. & S. Gage	Platinum, a = 5,172 Diameter in Inches	Platinum Nearest B. & S. Gage	German Silver, a = 5,230 Diameter in Inches	Ger. Silver Nearest B. & S. Gage	Platinoid, a = 4,750 Diameter in Inches	Platinoid Nearest B. & S. Gage	Iron, a = 3,148 Diameter in Inches	Iron Nearest B. & S. Gage	Tin, a = 1,642 Diameter in Inches	Tin Nearest B. & S. Gage	Tin and Lead Alloy, a = 1,318 Diameter in Inches	Tin and Lead Alloy Nearest B. & S. Gage	Lead, a = 1,379 Diameter in Inches	Lead Nearest B. & S. Gage
1	0.0021	43	0.0026	41	0.0033	39	0.0033	39	0.0035	39	0.0047	37	0.0072	33	0.0083	32	0.0081	32
2	0.0034	39	0.0041	38	0.0053	35	0.0053	35	0.0056	35	0.0074	33	0.0113	29	0.0132	28	0.0128	28
3	0.0044	37	0.0054	35	0.0070	33	0.0069	33	0.0074	33	0.0097	30	0.0149	27	0.0173	25	0.0168	26
4	0.0053	35	0.0065	34	0.0084	31	0.0084	31	0.0089	31	0.0117	29	0.0181	25	0.0210	24	0.0203	24
5	0.0062	34	0.0076	32	0.0098	30	0.0097	30	0.0104	30	0.0136	27	0.0210	24	0.0243	22	0.0236	23
10	0.0098	30	0.0120	28	0.0155	26	0.0154	26	0.0164	26	0.0216	24	0.0334	19	0.0386	18	0.0375	19
15	0.0129	28	0.0158	26	0.0203	24	0.0202	24	0.0215	23	0.0283	21	0.0437	17	0.0506	16	0.0491	16
20	0.0156	26	0.0191	24	0.0246	22	0.0245	22	0.0261	22	0.0343	19	0.0529	16	0.0613	14	0.0595	15
25	0.0181	25	0.0222	23	0.0286	21	0.0284	21	0.0303	20	0.0398	18	0.0614	14	0.0711	13	0.0690	13
30	0.0205	24	0.0250	22	0.0323	20	0.0320	20	0.0342	19	0.0450	17	0.0694	13	0.0803	12	0.0779	12
35	0.0227	23	0.0277	21	0.0358	19	0.0356	19	0.0379	18	0.0498	16	0.0769	13	0.0890	11	0.0864	12
40	0.0248	22	0.0303	20	0.0391	18	0.0388	18	0.0414	18	0.0545	15	0.0840	12	0.0973	10	0.0944	11
45	0.0268	21	0.0328	20	0.0423	18	0.0420	18	0.0448	17	0.0589	15	0.0909	11	0.1052	10	0.1021	10
50	0.0288	21	0.0352	19	0.0454	17	0.0450	17	0.0480	16	0.0632	14	0.0975	10	0.1129	9	0.1095	9
60	0.0325	20	0.0397	18	0.0513	16	0.0509	16	0.0542	15	0.0714	13	0.1101	9	0.1275	8	0.1237	8
70	0.0360	19	0.0440	17	0.0568	15	0.0564	15	0.0601	14	0.0791	12	0.1220	8	0.1413	7	0.1371	7
80	0.0394	18	0.0481	16	0.0621	14	0.0616	14	0.0657	14	0.0864	12	0.1334	7	0.1544	7	0.1499	7
90	0.0126	18	0.0520	16	0.0672	14	0.0667	14	0.0711	13	0.0935	11	0.1443	7	0.1671	6	0.1621	6
100	0.0457	17	0.0558	15	0.0720	13	0.0715	13	0.0762	13	0.1003	10	0.1548	6	0.1792	5	0.1739	5
120	0.0516	16	0.0330	14	0.0814	12	0.0808	12	0.0861	12	0.1133	9	0.1748	5	0.2024	4	0.1964	4
140	0.0572	15	0.0698	14	0.0902	11	0.0895	11	0.0954	11	0.1255	8	0.1937	4	0.2243	3	0.2176	3
160	0.0625	14	0.0763	13	0.0986	10	0.0978	10	0.1043	10	0.1372	7	0.2118	4	0.2452	2	0.2379	3
180	0.0676	14	0.0826	12	0.1066	10	0.1058	10	0.1128	9	0.1484	7	0.2291	3	0.2652	2	0.2573	2
200	0.0725	13	0.0886	11	0.1144	9	0.1135	9	0.1210	9	0.1592	6	0.2457	2	0.2845	1	0.2760	1
225	0.0784	12	0.0958	10	0.1237	8	0.1228	8	0.1309	8	0.1722	5	0.2658	2	0.3077	0	0.2986	1
250	0.0841	12	0.1028	10	0.1327	8	0.1317	8	0.1404	7	0.1848	5	0.2851	1	0.3301	0	0.3203	0
275	0.0897	11	0.1095	9	0.1414	7	0.1404	7	0.1497	7	0.1969	4	0.3038	1	0.3518	00	0.3413	0
300	0.0950	11	0.1161	9	0.1498	7	0.1487	7	0.1586	6	0.2086	4	0.3220	0	0.3728	00	0.3617	00

In the above table the fuses are supposed to be of the open type.

CHAPTER V

CUT-OUT PANELS AND CABINETS

In hardly any other branch of interior wiring have so great improvements been made as in the method of protecting the branch and main circuit wires by fuses.

This improvement has been not only in the fuse itself, but also in the method of inserting the fuse in the circuit and in making connections for the various conductors.

As stated in the chapter on fuses, one of the greatest objections to the Edison porcelain block type of cut-out was the manner of making connections with the conductors. These contacts were all of the screw type, and no lugs whatever were used.

Where stranded wires are used, this type of connection is very objectionable, as it frequently happens that only two or three strands of the conductor are in contact with the screw head or copper strap, and the rest are squeezed out and carry little or no current.

In 1892 the panel type of cut-out distributing boards was introduced. These panels consisted of a slab or tablet on which were mounted bus-bars and connecting bars for making the connections between the main wires and the branch circuit wires. In these boards fuse wire was used instead of the fuse plugs. All the connections in these early panel-boards were made at the back of the board — a method which was as dangerous as it was inconvenient. This type was soon followed by tablet or panel-boards having front connections for all the wires.

These panel distributing boards were placed in cut-out boxes, having the inner sides and doors lined with asbestos paper or slate. The first cabinets consisted of a simple box of general form and design, shown in Figs. 33, 34, and 35. The panel was screwed to the back of the box. With this type of cut-out cabinet it was necessary to bring each circuit opposite the corresponding connection on the panel-board, which, at times, was a difficult and expensive thing to do. For this reason they were shortly

followed by the double type of cut-out cabinet, shown in Figs. 36, 37, and 38. In this form of cabinet it is not necessary to bring the circuits to any particular point, although when it can be

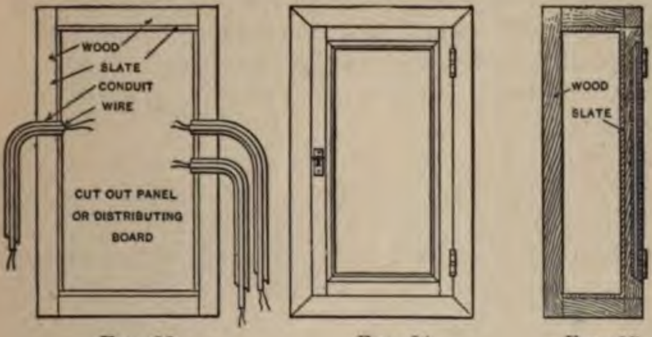


FIG. 33 FIG. 34 FIG. 35

accomplished without difficulty it is well to bring the circuits as near as possible to their respective points of connection. In many cases, however, it is necessary to bring the conduits in at the top or in at the bottom of the box, and in such cases the circuits can be extended to their proper points in the connection compartments, or "gutters," between the outer and inner boxes. The advantages of this method are obvious. As seen from the drawings, the door opens only on the panel, the "gutter" being

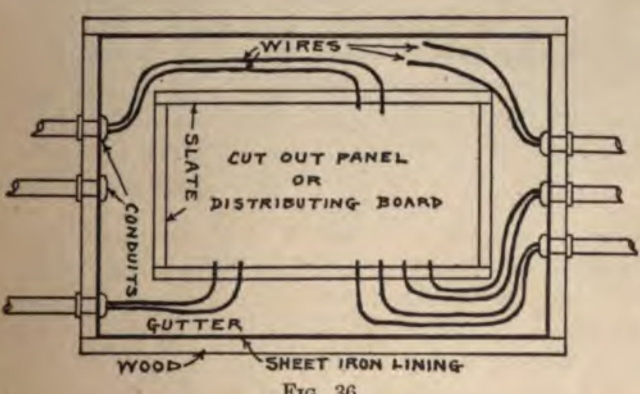


FIG. 36

covered by the trim of the box, which is fastened in place by wood screws. Whenever it is necessary to get at the wires between the conduits and the panel, it is necessary to remove the

trim of the cover. This method has now been in use for several years and has given better satisfaction than anything else yet devised for the purpose.

The present type of panel-board is arranged with bus-bars running vertically up and down the panel with cross connecting bars extending horizontally to the branch circuit or main connections. These horizontal bars are interrupted for the insertion of the fuses.

Three forms of fuses are used at the present time for the panel-board type of cut-out, i.e., the plug fuse, the link fuse, and the enclosed or cartridge fuse. Figs. 39, 40, and 41 show panel-boards with the plug, link, and cartridge fuses respectively.

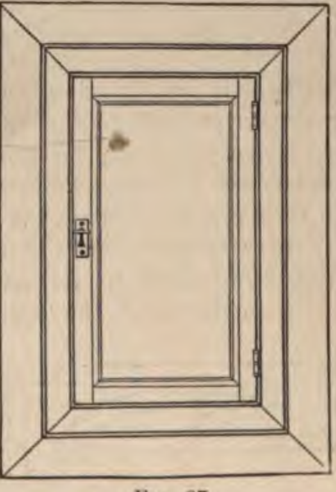


FIG. 37

FIG. 38

For conductors of sizes smaller than No. 8 B. &. S. gage, the connection is made by means of binding screws with copper washers. This connection is used for all the branch circuit conductors which are usually of No. 14 B. &. S. gage, although in a few cases No. 12 and even No. 10 B. &. S. gage conductors are used. Where the wire to be connected to the bus-bars is larger than the No. 8 B. &. S. gage, special copper lugs are provided for the purpose, the wires being inserted in a hole in the lug and then soldered, or, to use the wireman's terminology, "sweated" in place. This method of connection is a marked step in advance over the method used in the porcelain base fuse

blocks, where large wires are squeezed under binding screws and where in many cases only a portion of the conductor is in actual contact. This lug connection is, therefore, one of the advantages of the panel-board type of cut-out over the porcelain base fuse block.

Fig. 39 shows a two-wire panel adapted for the use of fuse plugs. The panel is shown enclosed in a wooden cabinet having a glass door. This type of panel is approved by the Board of

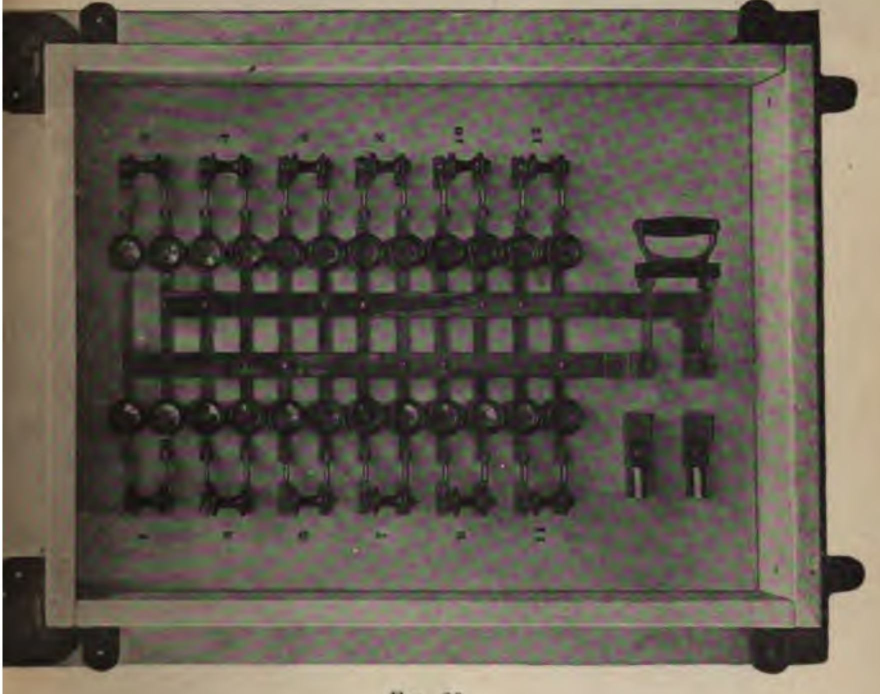


FIG. 39

Underwriters, and is preferred by some to the panel-board having open-link fuses. These new fuse plugs are also adapted to the cartridge type of fuse, as shown in Fig. 42. They are quite a little more expensive than link fuses, and it is sometimes difficult, on a large panel, to locate a blown fuse.

Fig. 40 shows a characteristic design of panel-board adapted for the use of link fuses. In this case the panel-board is of the three-wire type with a two-wire branch circuit. Provision is made for the feeder, or main, to supply the group of cut-outs, at

the bottom of the panel where lugs are provided for making the connection. No sub-main is supplied from the panel in this case.

Fig. 41 shows a type of panel-board adapted to cartridge fuses. Fig. 43 shows a cartridge fuse suitable for screw connection. Fig. 44 shows a cartridge fuse for spring clip connection.

Figures 45, 46, and 47 show four views of a cut-out panel

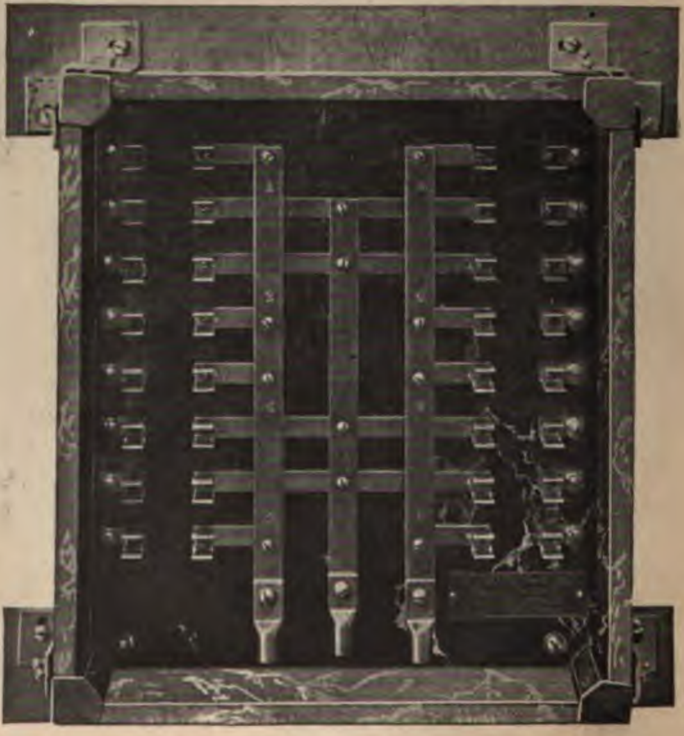


FIG. 40

and cabinet used at the R. H. Macy building, New York City. Fig. 45 shows an elevation and sectional view of the panel and cabinet. Figs. 46 and 47 show photographs of the cabine and panel in position.

These panels are two-wire and are equipped with cartridge fuses of the clip type. This type of panel-board and cabinet was originated by the writer, and was first made from his drawings and specification for the Macy building. The object of this

FIG. 41

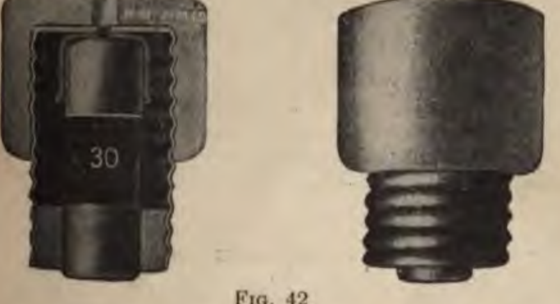


FIG. 42

FIG. 43

design is to render it possible to control each branch circuit (which supplied a single arc light in each case) by a push-button switch at the cut-out cabinet. In order to make it possible for

FIG. 44

the lights to be controlled by the floor-walkers, without allowing them access to the other portions of the panel, the cabinet is designed with a special arrangement of doors, as shown.

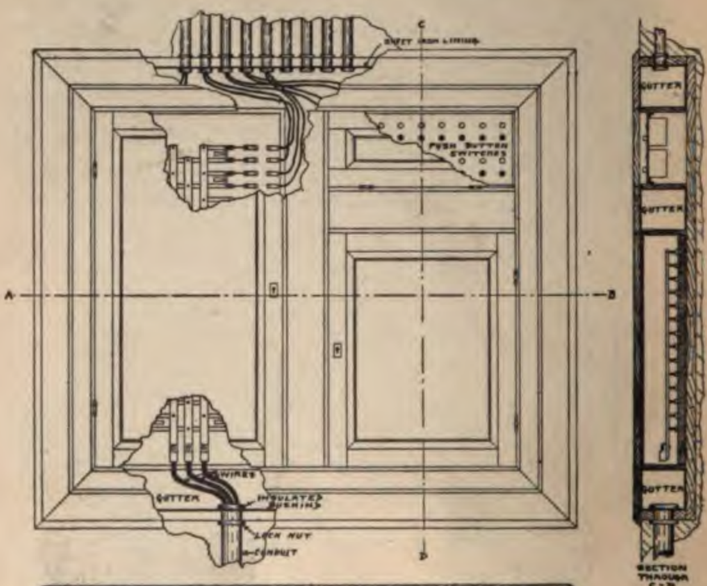


FIG. 45

The design consists of a separate cut-out panel arranged for enclosed fuses and having a separate push-button switch compartment at each side of the cut-out panel. The push-button switch is of a special type, and arranged for bottom connection

FIG. 46

FIG. 47

with the bus-bars as shown. The branch circuit wires, instead of being connected direct to the cut-out panel, were arranged to be connected to the short copper strip connected to the outer side of the switch in each case.

The switch compartment is lined with slate and in every case is provided with a separate door. By this arrangement it is possible to lock the fuse compartment and provide latches for the switch compartments.

If desired, locks may also be put on the doors opening into the switch compartments and separate keys may be given to the proper parties for this purpose, instead of having the doors provided merely with a latch. This arrangement has proven far more satisfactory than the usual arrangement where knife-switches are used by persons unskilled in the use of electricity, because with a push-button switch it is impossible to improperly open or close the circuit. With a knife-switch, however, a person not versed in electrical matters is very apt to close the circuit slowly or to partly close the switch, thereby causing arcing and ultimate destruction of the switch. The writer has known numerous cases where panel-boards have been practically destroyed by allowing persons unfamiliar with electrical appliances to have access to the panel-boards, and by controlling arc lamps by means of small knife-switches placed at the cut-out panels.

CHAPTER VI

OUTLET BOXES, OUTLET INSULATORS, ETC.

An outlet box is a device placed at an outlet for the purpose of providing a terminal for the conduits, and also a space for making the connections between the branch circuit wires and the outlet fixture or appliance. It is usually made of iron or steel, in two parts (box and cover).

The rules of the National Board of Fire Underwriters require an outlet box to be placed at all outlets where the conductors are run in conduit. The rule requiring the use of outlet boxes, and governing their use, is given under the head of Interior Conduits, as follows:

25 *d.* (Interior conduits.) Must be equipped at every outlet with an *approved* outlet box or plate.

Outlet plates must not be used where it is practicable to install outlet boxes.

In buildings already constructed, where the conditions are such that neither outlet box nor plate can be installed, these appliances may be omitted by special permission of the Inspection Department having jurisdiction, providing the conduit ends are bushed and secured.

24 A. *b.* (Armored cable.) Must be equipped at every outlet with an *approved* outlet box or plate, as required in conduit work. (See No. 49 A.)

49 A. Switch and Outlet Boxes.

a. Must be of pressed steel having a wall thickness not less than .081 inch (No. 12 B. &. S. gage) or of cast metal having a wall thickness not less than .128 inch (No. 8 B. &. S. gage).

b. Must be well galvanized, enameled, or otherwise properly coated, inside and out, to prevent oxidation.

c. Inlet holes must be effectually closed, when not in use, by metal which will afford protection substantially equivalent to that of the walls of the box.

d. Must be plainly marked, where it may readily be seen when installed, with the name or trade-mark of the manufacturer.

e. Must be arranged to secure in position the conduit or flexible tubing protecting the wire.

This rule will be complied with if the conduit or tubing is firmly secured in position by means of some *approved* device which may or may not be a part of the box.

f. Boxes used with lined conduit must comply with the foregoing requirements, and in addition must have a tough and tenacious insulating lining at least 1-32 inch thick, firmly secured in position.

g. Switch boxes must completely enclose the switch on sides and back, and must provide a thoroughly substantial support for it. The retaining screws for the box must not be used to secure the switch in position.

Outlet boxes are not required by the present rules for circuit work run in molding, or for wiring installed in flexible tubing like circular loom, for cleat work or for *knob and tube* wiring.

The advantages of an outlet box are: (1) It provides a satisfactory fire-proof terminal for the conduits. (2) The connections between the fixture and the branch circuit wire can be made in a space protected from plaster, dirt, etc. (3) By their use it is possible to make a neat finish, with plaster, wood, etc., around the outlet opening, which would otherwise be impossible. (4) The boxes being insulated inside, the possibility of *ground* or *short circuit* is greatly decreased at the points where these troubles are most apt to occur. (5) By their use, particularly in the case of side outlets, a suitable support for the fixture is more easily obtained.

Before the days of outlet boxes, when paper and brass armored conduits were used, the tubes were usually terminated at a wooden block having suitable openings for the conduits to enter, or else they were merely bunched together and allowed to project from the wall and were cut off after the plastering was completed. It was not until the days of iron-armored conduits that outlet boxes came into general use; in fact, iron conduits were used for a short time before the necessity for outlet boxes was generally recognized. With the introduction of iron conduit, however, the necessity for a suitable terminal at the outlet became evident, as it was impracticable to bend or cut the ends of the tubes, as had been the practice with the paper and brass armored conduits.

The first form of iron outlet boxes consisted of a hollow iron casting in one piece, with a circular opening in the front face and having only one of the sides open to receive the conduits. When conduits entered any other sides of the outlet box, it was neces-

sary to drill the box to receive them. These boxes were immediately succeeded by others of an improved type, having openings in the sides and back for the conduits. All the principal forms of outlet boxes may be roughly classified in two groups, viz., "Universal" outlet boxes and those designed for the specific purpose for which they are to be used. Under the first head are included those forms of boxes in which an opening may be made in any part of the box, so that, no matter from what direction the tube comes, a corresponding opening in the box may be more or less readily made without drilling. The other type of box is one in which openings are already made at certain points for the conduits to enter.

The advantages of the universal type are apparent. When they are used it is only necessary to state, in ordering the boxes, whether round or square boxes are wanted, and whether for gas and electric fixtures, or for electric fixtures only. Again, in these boxes the tubes may be brought into the box from any side, as it is possible to make an opening in any of the four sides or in the back; also, if the work be changed or if outlets be omitted, the boxes are good for future work, as they can be used under very nearly all conditions. Their disadvantage is the objection chargeable to all universal tools, namely, that they are admirably adapted for all cases but poorly suited to any one particular case. It is always necessary, in making a tool or device suitable for all cases, to compromise several desirable features in order to make it suitable for all conditions. However, this type of box has been greatly improved in the last few years.

The advantage of the other type is that, each box being designed for a specific purpose, it is especially arranged for those conditions, and neater and better work can therefore be obtained by its use; the disadvantage is that considerable trouble is involved in ordering them. It is necessary with this type of outlet box to carry a larger stock on hand, as changes are apt to occur, and unless a few spare boxes are carried in stock, the contractor is apt to run short of the particular design required. Where a number of boxes of the same kind are to be used, and where the conduits enter them in the same manner, it is better to use the special form in which the openings are already made. Where, however, the conduits enter the boxes in various ways, and where a few of each kind only are required, and particularly where the work is being done at a considerable distance from

the source of supply, the universal form is probably better. The cost of the Universal Outlet Box is slightly less than the other type.

Outlet boxes should be insulated inside with some adequate kind of insulating material. The best method of accomplishing this result is to have the inside of the box enameled with porcelain lining. The advantages of this are, that it does not rust or corrode, it has high insulation, and, being white, any flaws or defects in the insulation are readily discernible. Its disadvantages are, that it is liable to be chipped and cracked, and it is more expensive than other forms of insulation. Another insulating lining for outlet boxes is Japan enamel. If the enameling is properly put on and baked it forms a fair substitute for the porcelain lining.

All gas-pipes, fixture supports, etc., entering or placed inside of the outlet box should also be painted with insulating paint or compound. This tends to prevent any grounds, leaks, or "short circuits" at the outlet connections.

CHAPTER VII

FEEDERS AND MAINS

THE feeders and mains constitute the "trunk lines" of the distributing system through which the current is fed to the "branch circuits."

In this book, where the term feeder is employed, it is intended to refer to a conductor which begins at the switchboard or at the service supply and terminates at a center of distribution; this center of distribution may serve to supply either mains alone (in which case it would be a main center of distribution) or branch circuits, or it might supply both. Any prolongation of a feeder other than a branch circuit is called a main. Formerly the nomenclature included feeders, sub-feeders, mains, sub-mains, etc., but confusion resulted from the use of so many terms, and they have gradually dropped from use and the trunk lines are generally classed as either feeders or mains, their definition being usually as given above, when used in reference to interior wiring.

Before proceeding to adopt any scheme of feeding, it is well to consider in each case certain points which would influence the feeding system. As these points present important problems we will now proceed to note them, and then consider them in detail:

1. Control of groups of light (other than hall or night lights) from the main switchboard.
2. Control of hall lights from main switchboard.
3. Maximum number of lights that should be supplied by one feeder.
4. The best maximum limit for the size of the feeder conductors.
5. Portion of total loss to be allowed in the feeders and mains.

1. Control of groups of light (other than night or hall lights) from the main switchboard.

It sometimes happens that it is desirable or even necessary to control the lights on each floor (or a portion thereof) from the main switchboard. Where such is the case, the feeder system

must conform with this requirement and a separate feeder run to each floor (or group of lights).

As a rule, however, the feeder system may be laid out regardless of the control, so far as the room lights are concerned. In all cases, however, it is well to have each of the lower floors, up to and including the ground floor, on a separate switch, as these floors require light at a greater number of hours and at more unusual times than the other floors.

Wherever there is special lighting, such as the lighting of a "sign" clock dial, outside dome lights, or other decorative lighting, the lights should be provided with a separate distinct feeder controlled from the switchboard, because these lights are turned on and off at a set time from the switchboard.

In the case of a hotel, where the light may be required in any room at any time of day or night, of course this arrangement of feeders, so far as control is concerned, is of no importance, as it rarely happens that any of the switches controlling feeders supplying the bedroom floors are opened. They are closed the day the hotel opens, and are only opened in case of accident or other unusual circumstance.

Sometimes portions of buildings are rented on a contract basis, so that the tenant pays for the light he uses. Of course, the several portions could be metered separately by placing meters in the mains at the various floors or portions thereof. In such cases, however, where there is a considerable number of lights, it is best to provide a separate feeder for each of these portions, so that a meter may be placed on the feeder and the current consumed measured at the switchboard. This frequently happens in a business building having stores or a restaurant on the ground floor.

Fig. 48 is an example showing a six-story building having two stores on the ground floor, each of which is rented on the basis that the current be measured and paid for, in addition to the rent, the upper floors being supplied with current at any time of the day or night, thus making separate feeders unnecessary; also having an electric sign on the roof provided with a separate feeder, so that the sign may be turned on at dark and turned off, say, at one o'clock.

2. Control of the hall lights from main switchboard.

The control of hall or night lights from the main switchboard is one of the most important points to be considered in the arrangement of the feeder system.

In a private dwelling house it would hardly pay to have a separate feeder for the hall lights, as these lights are generally few in number and could readily be controlled by a few local switches, more readily, in fact, than by a feeder switch at the main switchboard. It may not be necessary even in a hotel, where there are attendants continually passing through the hall who could control the lights, either by local switches or by switches at the distributing center.

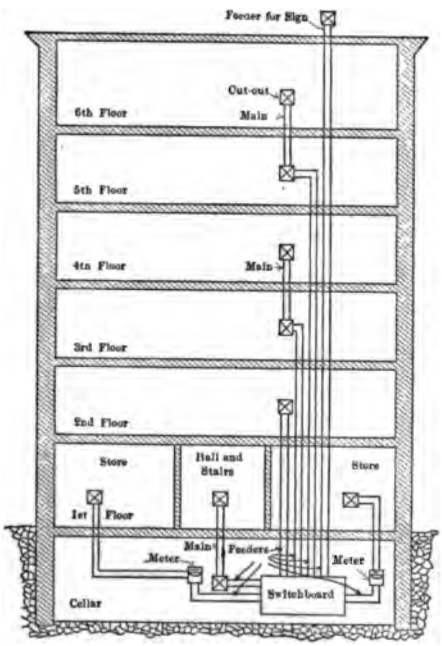


FIG. 48

In the majority of public buildings, however, the advantages of having separate feeders for the hall lights are so obvious that the problem is generally not whether there shall be separate feeders for the hall lights or not, but whether there shall be one or two sets of hall feeders. By having two sets of feeders for the hall lights, local switches for them may be dispensed with and they may be controlled entirely by the main switchboard. Of course, having two sets of hall feeders increases the cost of the wiring installation and makes the system more complex, but its possibilities for saving current are considerable. In a large

to find a suitable place to locate the meters on the various floors, but it has the advantage that the tenant can take his own meter readings as a check on the lighting company's inspector.

Figure 51 is an example of a factory building where a watchman is employed to make the "rounds" of the building at certain periods. Of course, light must be left on the stairs and hallways for this purpose, but it is required nowhere else. By having a separate feeder for the halls, the current may be cut off from the lofts at the switchboard, thus saving any current consumed by lamps that may have been left lighted by the employees when leaving the building.

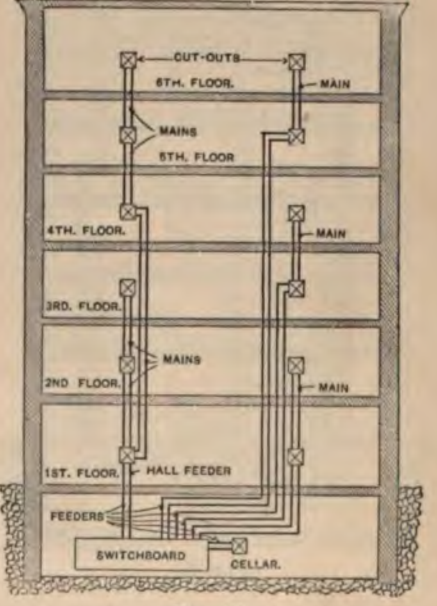


FIG. 51

3. Maximum number of lights that should be controlled by one feeder.

"Mark Twain" says he believes it is the best plan to put all your eggs in one basket and then "watch that basket." This would not be a good maxim to adopt in arranging your feeder system.

It very frequently happens that an engineer will be caught with one machine running almost up to its maximum capacity when a sudden rapidly rising load is seen to be coming on. Now

building with two sets of hall feeders. This arrangement very nearly corresponds (on a smaller scale) to the arrangement of the feeder system in a number of New York office buildings, whose electrical equipment was designed by the author. As a rule, an appreciable saving of current would usually result from having two sets of hall feeders in a building over five or six stories having more than six or eight hall lights on a floor.

Where a building receives its current supply from an outside source, the tenants paying for the current consumed (as meas-

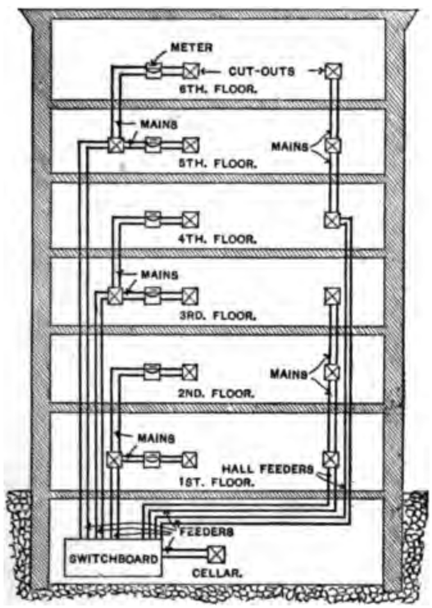


FIG. 50

ured by a meter), a separate feeder for the hall lights is indispensable, as the hall lights of course should be paid for by the owner of the building. Fig. 50 shows an arrangement of feeders in such a building, where each floor or loft may be rented to a separate tenant. It will be noted that here the meters are located on each floor instead of at the switchboard. Where a building is not of sufficient size to require a separate feeder for each floor, this is a much more economical arrangement than having them placed on the switchboard, as two or more floors may be fed by the same feeder. It is sometimes a difficult matter

mains. In any case, it is best to allow most of this loss in the feeders, as this tends to minimize the difference in voltage between lamps supplied by the same feeder. As a rule, the best results are obtained by having two thirds of the remaining loss in the feeder, and one third in the mains. In the case of four volts, total loss, this would mean two volts loss in the feeders and one in the mains and one in the branch circuits. Where the total loss was three volts there would be a volt and one third in the feeders, two thirds of a volt in the mains, and one in the branch circuit. Where the total loss was more or less the same ratio might hold good.

In discussing feeders and mains no special mention has been made of mains. Inasmuch, however, as a main may be considered as a prolongation of a feeder in the nomenclature we have adopted, what applied to a feeder would, with certain modifications, also apply to a main.

Having discussed the various points to be considered in adopting a system of feeders and mains, let us suppose we have reached a point in laying out the wiring where the branch circuit work is mapped out, the location of the various distributing centers and rising shafts has been decided upon, and there only remains the planning of the arrangement of the feeders and mains.

If the building has more than one story, the first thing to be done is to make an elevation of the building, showing the height and number of stories. On this elevation the various distributing centers should be indicated diagrammatically, but with a view to keeping their relative arrangement as near as possible to their actual arrangement on the different floors.

Having done this, it is necessary to decide two questions before proceeding further. These are, first, whether the hall or public lights will be controlled separately or together with the private lights from the main switchboard, because the settlement of this question will affect the arrangement and the number of the feeders and possibly of the mains. Let us first consider those cases where no distinction is made (so far as the feeders and mains are concerned) between the private and the public lights. The second question to be decided is whether there will be several floors (or portions thereof) supplied by one feeder, or whether there will be a separate feeder for each floor. We will first assume that there will be a separate feeder for each floor.

With our elevation and the floor plans before us, we proceed

to mark at each distributing center the number of lights supplied by the branch circuits starting from that center. This being done, a tentative lay-out of the mains running from the feeder center to the various sub-centers should be made.

Having done this, the next step is to find the number of lights supplied by the feeders and the mains. In the case of the feeders this is equal to the sum of all the lights supplied through the distributing centers on the floor, since we are now considering that they are all supplied by one feeder. In the case of a main, the load is, of course, equal to the number of lights supplied through the distributing centers, which are fed either by the main directly or by a prolongation of the main.

Having obtained the load of the feeders and mains, the next step is to get their estimated length. To do this, the horizontal length is first obtained by reference to the floor plans; the vertical length is estimated from the elevation of the building. These give us the apparent length of the feeder, and are accurate enough for the purpose of calculating the "loss" or "drop" and the size of wire. For the purpose of estimating the cost of the feeder, however, it is not sufficient. To get the actual length of the feeder we must try to conceive the exact course or route of the feeder, taking into consideration all deviating bends, off-sets, etc., making allowances for going around or under any obstructions, and also for connecting at each end of the wire. Even after having done this, experience shows that it is necessary to add about 5 per cent for slack, etc., to the estimated length thus obtained, in order to get the real length. If the building is already built, it is much the better plan to get these lengths directly from the building.

Next comes the question of the distribution of the "loss" or "drop" in voltage among the various conductors from the switchboard to the lamp.

Having determined on the loss to be allowed in the feeder, we have the three necessary factors for determining the size of wire required for the feeders and mains. These factors are the current in amperes (or the number of lamps), the length in feet (one way), and the loss (in volts) to be allowed. In another chapter we have fully explained the method and have given the formulas for calculating the size of conductors and the loss in the same.

Before calculating the size of the feeders, it is well to get the

data necessary for calculating the size of mains. This is done in a similar manner to that referred to above in getting the data for the feeders. A preliminary arrangement of the mains has presumably already been made, and the calculation of the feeder and the mains should be made conjunctively, so that if it be found desirable, the loss that was allowed for the feeder may be increased and the loss allowed for the mains correspondingly decreased, or vice versa. It will frequently be found that a new arrangement of the mains will give better results as to size or loss than the original arrangement.

At this point it must be borne in mind that in cases where the current supply is derived or liable in the future to be derived from both a two-wire system or a three-wire system, it is well to make the feeders and mains three-wire, with the neutral conductor equal to the combined capacity of the two outside conductors, the latter being connected together when used on the two-wire system. Of course, this does not effect any saving in the copper, such as occurs in the use of a three-wire system, because the total weight of the copper would have to be the same as in a straight two-wire system. As a matter of fact, the cost of a three-wire system of this kind is slightly greater than a corresponding two-wire system because the weight and consequently the cost of the copper is the same; but the cost of insulating and installing three conductors is greater than the cost of insulating and installing the corresponding weight of copper in two conductors. The increased cost of a three-wire system of this kind over the corresponding two-wire system (having the same weight of copper) has been found to be approximately 10 to 20 per cent.

Figures 52 to 56, inclusive, show arrangements of mains where there is a feeder for each floor and where there are several distributing centers on the floor, all of which are supplied from the feeder center by means of mains. Each of these figures, of course, shows but one floor.

Figure 52 is an example where the feeder center is located in about the center of the building and supplies two distributing centers on each side of it. This arrangement of mains is ideal. The fuses at the origin of the mains are all located at one point (the feeder center), which simplifies matters when one of the main fuses blows, it being easier to discover the location of that particular fuse if it be known that all the main fuses on the floor

are located in one cabinet. This arrangement also gives a uniform potential at each of the four distributing centers. Furthermore, where there is a considerable number of lamps supplied at the various centers, it keeps the mains, and consequently the conduits down to those sizes which can be readily installed in

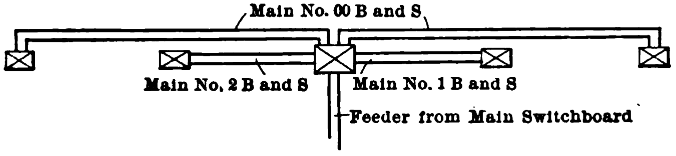


FIG. 52

the available space between the beams and the finished floor. Where, however, there are only a few lamps supplied at each center, it has the disadvantage of being slightly more expensive than the arrangement shown in Fig. 53. This is a very fair arrangement, and is the one generally adopted where the loads on the mains are light. What disadvantages it has are obvious when compared with the arrangement shown in Fig. 52.

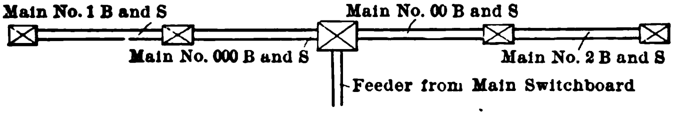


FIG. 53

Figures 54, 55, and 56 show arrangements of mains where the feeder distributing center is located at one end of the building, the other centers being all located on one side of it. Fig. 54 shows a very poor arrangement of mains. Its disadvantage is that, owing to the rule of the Fire Underwriters, it is necessary to place a "fuse at every point where a change is made in the size

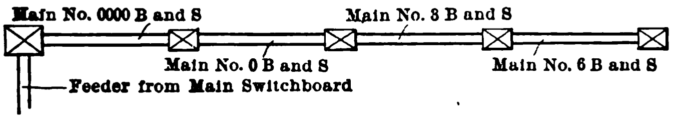


FIG. 54

of the wire (unless the cut-out in the larger wire will protect the smaller)," and consequently to place a number of fuses in "series," located at different points. This always causes delay and confusion in time of "trouble." It is well to keep the number of

fuses in "series" down to the lowest possible point, and also to centralize them as far as possible. This arrangement also has the disadvantage of making it difficult to get a uniform distribution of potential at all the distributing centers. Its sole apparent advantage is that of economy.

Figure 55 shows a similar arrangement to that of Fig. 54, but slightly better in that we have only two different sizes of

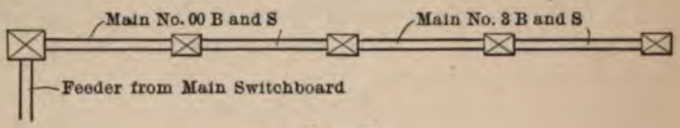


FIG. 55

main wires and have, therefore, diminished the number of fuses on the mains just one half. This method is slightly more expensive, but for the reason given is preferable to the former.

Fig. 56 shows an arrangement of mains which is preferable to the arrangement shown in either Fig. 54 or in Fig. 55.

The next case to consider is that where a feeder is not limited to supplying one floor only, but may supply two or more floors. This gives more scope for the arrangement of the feeders and the mains. In such instances there may be several rising places for the feeders; in fact, if suitable rising shafts could be found, a

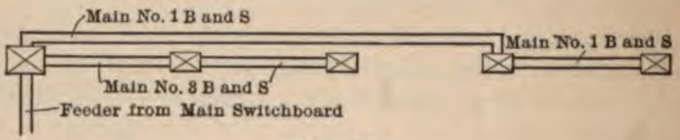


FIG. 56

good arrangement would be to have the distributing centers placed near these rising shafts at each floor, with a set of feeders rising at each one of the shafts and feeding several floors at each point by means of vertical mains. Where it is not necessary to control each floor separately, this generally makes the cheapest and best arrangement.

Figures 57 to 60, inclusive, show different arrangements of feeders and mains of this type (i.e., where a feeder may supply more than one floor). Their relative advantages and disadvantages are evident from what has been already said in regard to the arrangements shown of the first type. (See Figs. 52 to 56.)

'igs. 57 and 58 are examples of cases where there are no horizontal nains at all. This is a good feature, particularly where the mains ire large, as it keeps large sizes of conduits off the floor. It is iearly always easier to find room vertically for large sizes of onduits than it is to find room for them between the beams ind the finished floor. The data for feeders and mains of this type is, of course, procured in a manner exactly similar to that idopted in the previous case.

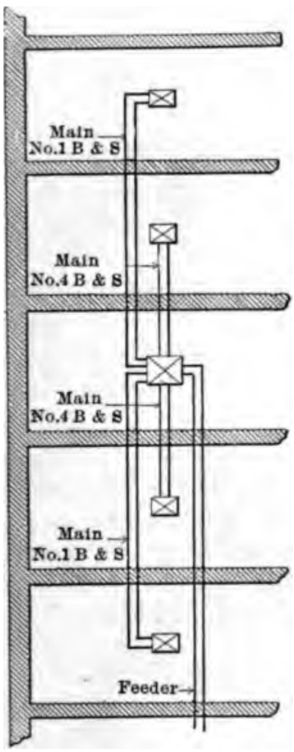


FIG. 57

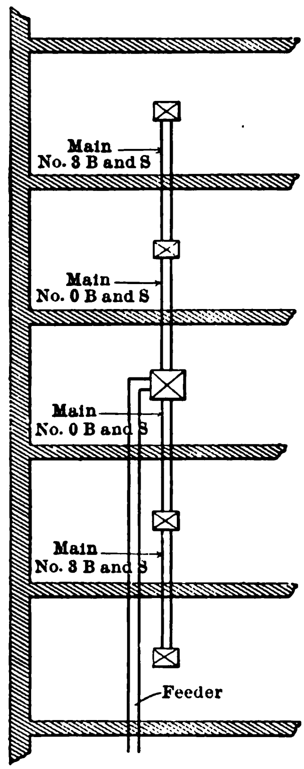


FIG. 58

The only remaining case to be considered is that in which separate feeders are required for the hall or public lights. What has been said above in regard to the feeding systems in general will also apply, with slight modifications, to the hall feeder. The hall feeders, however, usually have much lighter loads, and consequently are smaller in size. It is very rarely necessary or desirable to have a separate feeder for the hall lights on each

floor, but one feeder can easily supply the hall lights on several floors. In fact, usually the only limit to the number of floors that may be supplied by one feeder is the refinement of control desired from the main switchboard.

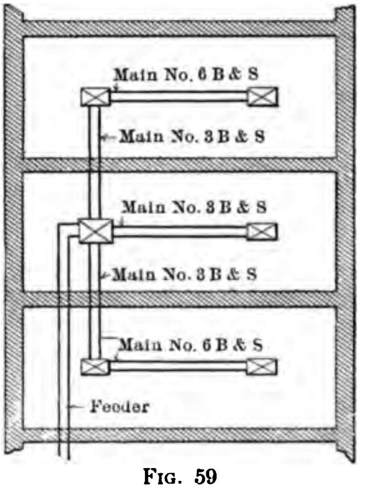


FIG. 59

We have already mentioned that it is sometimes wise to have two sets of feeders for the hall lights, one set controlling a portion of the hall lights on each floor, the other set controlling the remainder. The character and use of the building and the number of public lights required usually serve as guides for determining or not if this provision is necessary. Of course, in procuring the data for the feeder and mains of this type the number of hall lights is kept separate from the room lights.

CHAPTER VIII

TESTING OF INSULATION RESISTANCE, ETC.

AFTER the wiring installation has been completed, and in many cases before it has been completed, it is necessary to make tests of the various circuits, fixtures, panel-boards, etc. Wherever possible, an insulation test should be made of the wiring before the fixtures are installed and connected. The fixtures should, in all cases, be tested before they are installed, so that any defects in their wiring may be discovered and repaired before being connected. After the fixtures are installed an insulation test should be made between the wires, and also between the wires and the ground.

For the purpose of testing, a magneto is very largely used. This instrument is really a small, alternating-current dynamo (having its field produced by permanent magnets) operated by hand. A magneto may be turned into a direct-current instrument by means of a commutator, and this type of instrument is to be preferred to an alternating-current instrument. As a rule a magneto is not to be recommended for testing, as it is not very accurate and in many cases gives surprising results. It is a well-known fact that with an alternating-current magneto it is possible to ring through either a cable or a conductor, provided the latter has sufficient capacity. This is due to the fact that the cable, if long enough, acts as a condenser, and that the magneto, if an alternating-current machine, rapidly charges and discharges the cable in alternate directions, thus causing the bell connected in the magneto circuit to ring, and, apparently, indicating a ground or short circuit on the cable. This has often misled wiremen and inspectors to believe that the cables have been grounded when they were really very free from grounds or leaks. For this reason some other type of instrument is generally to be preferred to the magneto. For some work, however, it can be used to advantage, such as for testing fixtures, etc.

The best method of testing insulation resistance for ordinary

purposes in buildings is the voltmeter method. In this method the instrument used is an ordinary, direct-current voltmeter, having a scale of, say, zero to one hundred and fifty volts, and a box of silver chloride cells or ordinary dry batteries. The resistance of the voltmeter must be known, but usually the resistance of the battery is negligible. Figs. 62, 63, 64, and 65 show the method of making the connections for this test. The first step is to connect the batteries directly to the voltmeter and take a direct reading of the voltage of the cells. This connection is shown in Fig. 62. The next step is to place the insulation resistance, "whether it be in wires, dynamos, panel-boards, etc.," in series with the voltmeter and the cells, as shown in Figs. 63, 64, and 65. The voltage indicated on the instrument now shows, indirectly, the amount of leakage or insulation resistance. The method of calculating the insulation resistance is as follows:

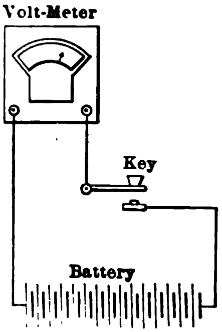


FIG. 62

Let us indicate the voltage of the cells connected directly to the voltmeter by the letter E, and the reading of the voltmeter with the insulation resistance in series by the letter E′; the re-

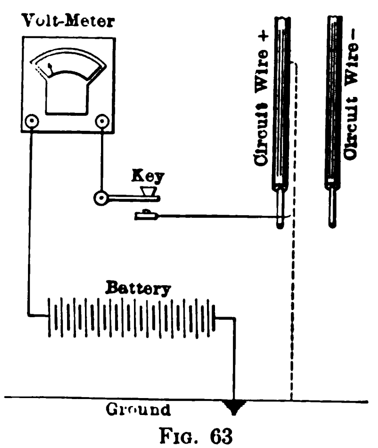


FIG. 63

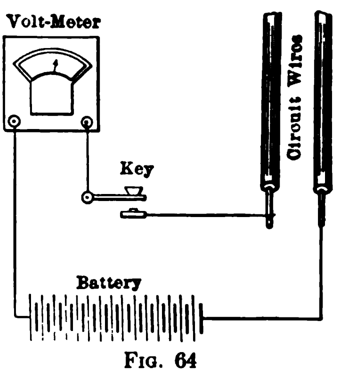


FIG. 64

sistance of the voltmeter by R and the insulation resistance which we wish to determine by the letter R_x. We know that the voltage is inversely proportionate to the resistance; that is, if

the resistance be increased the voltage indicated on the voltmeter will be correspondingly decreased. Now, the resistance in the first case is merely the resistance of the voltmeter and the battery; as the resistance of the battery is usually very small with respect to the voltmeter, we can neglect this throughout the calculations. When the insulation resistance is placed in the series with the voltmeter and the battery, the resistance is then

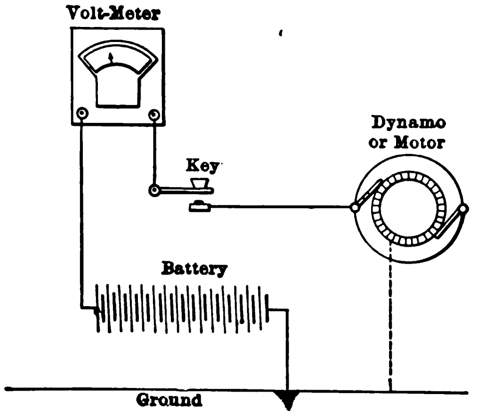


FIG. 65

that of the voltmeter, the battery (which will be neglected), and the insulation resistance. In putting this in simple mathematical form, we have

$$E : E' = R + R_x : R$$

From the theory of proportions then

$$E'R + E'R_x = ER$$

transposing

$$E'R_x = ER - E'R = R(E - E')$$

and

$$R_x = \frac{R}{E'}(E - E')$$

or in other words, the insulation resistance is equal to the resistance of the voltmeter multiplied by the difference between the first reading (that is, the voltage of the cells) and the second reading (the reading of the voltmeter with the insulation resistance in series with the voltmeter cell), divided by the second reading.

In order to make this clear to those unfamiliar with mathematics and formulæ generally, we will take a concrete example. Let us suppose the resistance of the voltmeter (R) to be ten thousand ohms (10,000), and the voltage of the cells (E) to be 40 volts, as indicated when connected to the voltmeter. Let us also suppose that we are making an insulation test between the feeders in a building, and that when the connections are made, as shown in Fig. 63, we get a reading of five (5) volts (E') on the voltmeter. From the formula $R_x = R\ \frac{(E - E')}{E'}$ we get, by substituting the readings for the letters, $R_x = 10{,}000 \times \frac{40 - 5}{5}$, which is equal to $10{,}000\ \frac{(35)}{5} = 10{,}000 \times 7 = 70{,}000$ ohms.

Another method of making insulation resistance tests is known

Fig. 66

as the bridge method, in which a resistance box is used, containing a small galvanometer. An instrument of this sort is shown in Fig. 66. The objections to this are:

First. That it takes considerably longer to make an insulation test by this method than it does by the voltmeter method. In many cases an insulation test must be made very quickly. For example, in a building where current is being used and it is necessary to shut off the current in order to make the test; in such

cases it is of great advantage to be able to take the reading immediately and turn the current on again. By the voltmeter method everything can be prepared before the current is shut off and the reading taken in one or two seconds, and the current may then be turned on instantly. With the bridge method it sometimes takes several minutes to obtain the same results.

Second. It requires more experience to use a bridge than to use a voltmeter, and the person making the test is less apt to become confused by the voltmeter method than by the bridge method, as it is necessary to adjust the galvanometer needle so that it will swing freely, before making the test.

Recently, a direct reading Ohmmeter has been brought out in this country, where the resistance can be read directly on a

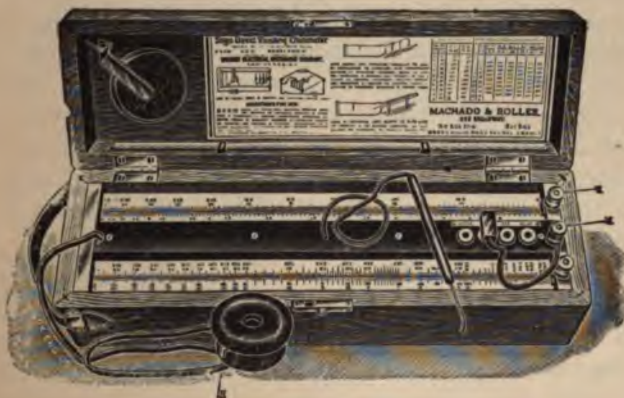


FIG. 67

scale. Both this instrument and the resistance bridge are more adapted for making resistance tests from one tenth of an ohm to one hundred thousand ohms than for making insulation tests where the resistance is liable to be a million ohms, or higher.

Fig. 67 shows a direct reading Ohmmeter. An additional advantage which the voltmeter has over the other methods is, that a voltmeter is usually necessary for other purposes, in making a test on the equipment, such as taking the voltage of the dynamos, calibrating the voltmeters on the switchboard, etc., and therefore would be available for these purposes as well as for making the insulation test. In making the test on the wiring of an installation, the best method of procedure is to turn off, or remove, all of the lamps, but to turn on all push button and knife switches;

to have all circuits properly connected and fuses inserted, and then to make a "bunch" test of all the feeders, mains, and branch circuits from the point where they start. A test should first be made between the conductors themselves; that is, in a two-wired system between the positive and negative leads and in a three-wired system between the two outsides and between each outside and the middle conductor. Then a ground test should be made between each of the two conductors, in the two-wired system, or between each of the three conductors in the three-wired system, and the ground. If a short circuit between the conductors, or a leakage between the conductors and the ground, be discovered, the proper method of locating the trouble is by the method of elimination. To accomplish this end, each of the feeders, or mains, is successively cut out of circuit by opening the switch (or removing the fuse) controlling the same. When, by opening a certain circuit, the short circuit, or ground, disappears, of course the trouble is known to be on that feeder or main. By following this main up to the various centers of distribution through the building, the center of distribution at which this trouble is located can be discovered; and in similar manner the branch circuit and the outlet at which the trouble exists can be found.

In many cases it will be found that the slate used in the panel-boards for cut-outs contains metallic veins and that a leakage will result between the bus-bars. For this reason, it would be well if all panel-board makers would test their panel-boards before shipping them from their shops, as it is usually impossible to remove this trouble, and a new panel-board must generally be substituted for the one found to be defective. As a rule, most short circuits and grounds will be located at the outlets, where the wiring connects with the fixtures.

The insulation resistance of an installation should be proportionate to the amount of wiring and the number of fixtures, etc., connected. The rules of the National Board of Fire Underwriters require an insulation resistance depending upon the amount of current supplied by the various conductors. Their rule (No. 66) covering this point requires an insulation resistance between conductors, and between all conductors and the ground (not including attachments, sockets, receptacles, etc.), of not less than the following:

66. Insulation Resistance.

The wiring in any building must test free from grounds; i.e., the complete installation must have an insulation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.) not less than that given in the following table:—

Up to 5 amperes	4,000,000 ohms.
Up to 10 amperes	2,000,000 ohms.
Up to 25 amperes	800,000 ohms.
Up to 50 amperes	400,000 ohms.
Up to 100 amperes	200,000 ohms.
Up to 200 amperes	100,000 ohms.
Up to 400 amperes	50,000 ohms.
Up to 800 amperes	25,000 ohms.
Up to 1,600 amperes	12,500 ohms.

The test must be made with all cut-outs and safety devices in place. If the lamp sockets, receptacles, electroliers, etc., are also connected, only one half of the resistances specified in the table will be required.

CHAPTER IX

WIRE CALCULATIONS

FOR the benefit of the more practical reader, to whom mathematical symbols are more or less confusing, we will try to make the problem of calculating the size of wire as simple as possible, and will, therefore, make the consecutive steps as gradual and detailed as may be necessary to gain this end.

We know that the resistance of a wire increases as the length increases, and decreases as the area (i.e., the cross-section) increases. If we know the length (measured in feet) and the cross-section or area (measured in circular mils) of any piece of wire, we can calculate its resistance, provided we know the resistance of a wire 1 ft. long and 1 mil (i.e., 1-1000 in.) in diameter.

The resistance of a "mil foot" (as it is called) of wire has been determined by tests (Dr. Matthiessen) in the case of pure (soft) copper wire to be equal to 9.5878 (international) ohms at 0° C. (32° F.). This figure corrected for an ordinary temperature for operating conditions and for copper having 98 per cent conductivity of pure copper, would correspond to 10.8 ohms at 25° C. (77° F.). This figure is obtained by adding to the resistance at 0° C. (9.5878) the figure obtained by multiplying the resistance at 0°C (9.5878) by the rise in resistance per degree Centigrade (called the temperature coefficient which is equal to .0042 per degree Centigrade) multiplied by the number of degrees rise and dividing by 98 % (conductivity). Thus: $[9.5878 + (9.5878 \times .0042 \times 25°)]$ divided by .98 equals 10.80.

The resistance of any conductor is therefore equal to its length in feet, divided by the area in circular mils multiplied by the resistance per mil foot, which we calculated is 10.8 ohms; that is

$$R = \frac{l}{A} \times 10.8 \text{ ohms.} \tag{1}$$

where R = resistance of the conductor in ohms.
l = total length of conductor in feet.
A = area in circular mils.

Now, from Ohm's law we know that the loss in volts (e) in a conductor is equal to the current multiplied by the resistance of the conductor, or

$$e = I\,R$$

Placing in this equation the equivalent value of R in the first equation, we get

$$e = \frac{I \times l \times 10.8}{A}; \qquad (1)$$

or expressed in words, formula (1) means that the difference in voltage ("drop") between the beginning and end of a circuit is equal to the current flowing through that circuit, multiplied by the total length (in feet) of the conductor, divided by the area (in circular mils) of the wire, and multiplied by the resistance of one mil foot of wire.

Now, as the length of a circuit is generally given as the distance measured one way (i.e., one half of the length of wire constituting the circuit) it would be simpler to substitute this quantity, which we will represent by the letter L, in the formula, l, of course, being equal to twice L; that is,

$$e = \frac{I \times 2 \times L \times 10.8}{A} \qquad (2)$$

Now, as we have two constants, namely, 2 and 10.8, it will make the formula simpler if we multiply them together; thus,

$$e = \frac{I \times L \times 21.6}{A} \qquad (3)$$

Remember that L is the distance one way, or the length of one leg of the circuit, and that we still get the resistance of both legs of the circuit in the formula, because this distance is multiplied by the factor, 2, which now forms part of the constant, 21.6.

The formula, as above expressed, is used where the current, I, to be carried the distance, L, and the area of the wire, c.m., are all known, and we wish to determine the loss in voltage in the circuit. If we wish to find the size of wire required where the loss, length of circuit, and current carried are given, we can, by transposing the terms, get the formula in this form:

$$A = \frac{I \times L \times 21.6}{e} \qquad (4)$$

or, if we wish to determine the current that may be carried through a certain size of wire, where the distance and loss are fixed, we would use the formula in the following form:

$$I = \frac{A \times e}{L \times 21{\cdot}6} \tag{5}$$

in a similar manner, if we wished to determine the length that a circuit might be and produce a given loss with a given current in a fixed size of wire, the formula would be:

$$L = \frac{A \times e}{I \times 21.6} \tag{6}$$

If, however, instead of dealing in amperes, we had lamps to consider in our calculations, it might be simpler (where a number of calculations, involving lamps taking the same quantity of current, were to be made) to substitute a value for lamps in formula 4. The current in any case would be equal to the number of lamps multiplied by the current used by each lamp, or

$$A = \frac{N \times i \times L \times 21.6}{e}$$

where $N =$ number of lamps, $i =$ amperes or fraction thereof per lamp.

(Note: It must be remembered in all the above equations that e represents the loss in volts and is not the line voltage.)

In the case of a 16-c.p. lamp (using 3.5 watts per c.p.) the current required per lamp, burning at 116 volts, would be .48. Representing the number of lamps by N, formula 4 would become:

$$A = \frac{N \times .48 \times L \times 21.6}{e} \tag{7}$$

In a similar manner we could change the formula, for lamps, taking any number of amperes or fractions thereof.

The loss e, in volts, is always a proportionate part of the line voltage E; and the ratio $\frac{e}{E}$ may be used to represent the loss in terms of a percentage P, of the line voltage, thus:

$$P = \frac{e}{E}\ 100$$

whence

$$e = \frac{P \times E}{100}$$

Substituting this value of e in formula (4) we have a formula which gives the loss in percentage instead of in volts:

$$A = \frac{I \times L \times 21.6}{\frac{P \times E}{100}} = \frac{I \times L \times 2160}{P \times E} \qquad (8)$$

It frequently happens that it is desired to make the calculation in terms of power transmitted expressed in kilowatts. Since the power in watts is equal to the current multiplied by the voltage, W (Watts) $= E\ I$, we can obtain a formula in terms of watts transmitted, by multiplying both the numerator and denominator by E, thus:

$$A = \frac{E \times I \times L \times 2160}{P \times E \times E} = \frac{W \times L \times 2160}{P \times E^2} \qquad (9)$$

We have gone into the derivation of the above formulas with such minute detail as to run the risk of being wearisome, but wiremen who frequently have occasion to calculate the loss in circuits either do not know the formula, or are so puzzled by terms of the formulas, that they are unable to use them intelligently. Then again, many of those who use these formulas continually do not know what the constants signify, nor how they are derived.

Of course, there are tables, charts, and slide rules innumerable, but as a rule they are either inaccurate or more difficult to use than the formula. Nearly all of them are good only within certain narrow limits of length, current, and drop. A slide rule, however, has been devised by C. O. Mailloux that is extremely accurate, and has various adjustments for temperature, conductivity, etc., and is very valuable as a time saver in making wire calculations.

Having derived the formulas, let us now apply some of them.

For the sake of clearness, it may be well to state the principal formulas and to show an example applying the formula in each case.

The symbols used in the following formulas are as follows:

A = size of wire in circular mils.

e = loss in volts.

E = voltage of circuit at (distant) end.

L = length of the circuit (one way) in feet (that is, the length of one leg of the circuit).

N = number of lamps.
i = amperes (or fraction thereof) required by each lamp.
P = loss in per cent.
W = total watts delivered at end of circuit.

1. Given the current to be carried, the distance, and loss to be allowed, find the size of conductor.

$$A = \frac{I \times L \times 21.6}{e}$$

Example: A two-wire feeder must carry 200 amperes a distance of 300 feet with 3 volts loss. What is the size of conductor? Substituting,

$$A = \frac{200 \times 300 \times 21.6}{3} = 432000 \text{ C.M.}$$

circular mils. (Note: Two 450,000 circular mil conductors, being the nearest commercial size, would be used for this feeder.)

2. Given the size of conductor, the current to be carried, and the distance in feet, what would be the loss in volts?

$$e = \frac{I \times L \times 21.6}{A}$$

Example: A two-wire feeder of two No. 0000 B. & S. G. (211,600 C.M.) conductors, carrying 100 amperes, a distance of 150 feet. Substituting,

$$e = \frac{100 \times 150 \times 21.6}{211{,}600} = 1.5 \text{ volts}$$

3. Given the size of conductor, and the distance in feet, how many amperes can we carry with a given loss?

$$I = \frac{A \times e}{L \times 21.6}$$

Example: A two-wire feeder of 300,000 circular mils, a distance of 500 feet. How many amperes can be carried with 5 volts loss?

$$I = \frac{300{,}000 \times 5}{500 \times 21.6} = 139 \text{ amperes}$$

4. Given the size of conductor, and the current, to find the distance it may be carried with a given loss.

$$L = \frac{A \times e}{I \times 21.6}$$

Example: A two-wire feeder of No. 4 B. & S. gage (41,740 c.m.), carrying 50 amperes. How many feet can it be carried with 2 volts loss? Substituting,

$$L = \frac{41{,}740 \times 2}{50 \times 21.6} = 77 \text{ feet}$$

5. Given the number of lamps to be supplied, the distance and the loss in volts, to find the size of conductor.

$$A = \frac{N \times i \times L \times 21.6}{e}$$

Example: A two-wire feeder must carry one hundred 16-candle-power, 120-volt 3½-watt lamps a distance of 150 feet, with a loss of 2.5 volts, to find the size of conductor. (Note: One 16-c.p., 3½-watt lamp would take 16 × 3.5 watts = 56 watts, or $\frac{56}{120}$ = .47 amperes, which corresponds to i in the formula.) Substituting,

$$A = \frac{100 \times .47 \times 150 \times 21.6}{2.5} = 60{,}912 \text{ C.M.} = \text{No. 2 B. \& S. gage}$$

(next largest size).

6. Given the power to be carried in watts, the distance and the loss in percentage of the applied voltage, to find the size of conductor.

$$A = \frac{W \times L \times 2160}{P \times E^2}$$

Example: A two-wire feeder must carry 25,000 watts (25 K.W) a distance of 300 feet with a loss of 3 per cent, the voltage between conductors being 120 volts, to find the size of conductor. Substituting,

$$A = \frac{25000 \times 300 \times 2160}{3 \times (120)^2} = 375{,}000 \text{ C.M.}$$

7. Given a three-wire feeder, the current to be carried, the distance, and the loss to be allowed, find the size of conductors.

Example: A three-wire feeder must carry a total load, 200 amperes (in lamps balanced on each side of the neutral conductor), a distance of 300 feet, with a maximum loss of 3 volts in the potential across the outside conductors. What size of conductors would be required?

It is evident that if the three-wire system were balanced, the maximum load carried by the outside conductors would be 100 amperes, as the load (of 100 amperes) on one side would be in series with the load (of 100 amperes) on the other side. Therefore $I = 100$ amperes. Substituting in formula,

$$A = \frac{I \times L \times 21.6}{e}$$

where I = load on one side of system when load is balanced,

$$= \frac{100 \times 300 \times 21.6}{3} = 216{,}000 \text{ C.M. or practically No. 0000}$$

B. & S. G.

Inasmuch as there is a possibility of the neutral carrying the same load as either outside conductor, if a fuse should blow on either outside conductor, and also since the rules of the National Board of Fire Underwriters require it for interior wiring, it is necessary to use a neutral conductor of the same size as the two outside conductors. Hence, three conductors of No. 0000 B. & S. G. would be required for this feeder. Of course, if the feeder did not come under the insurance requirements, chances might be taken on using a smaller conductor for the neutral. (Note: The above calculation was made on a loss of 3 volts across the outside conductors. If the load is balanced, the drop in voltage on the lamps would be one half of the total drop, or $1\frac{1}{2}$ volts, as the loss would be distributed equally between the two sides. If, for any reason, such as the blowing of a fuse, one side of the three-wire circuit were disconnected, the current flowing through the other side would be the same, and the total loss in lamps on this side would then be three volts instead of one and one half volts, because while the total loss would be the same, it would not be divided between the two sides. The possibility, however, of one side being entirely disconnected is slight, and even though it did occur it would be for a short time only; it would, therefore, be foolish to make the calculation on such a basis. Of course, in a feeder which was badly unbalanced, the loss on the heavily loaded might frequently be more than one half of the total loss (across the outside) that would exist if the load were evenly balanced. For instance, if in the above case there were 50 amperes on one side, and 100 amperes on the other side, the drop in voltage on the lamps on the loaded side would be obtained by calculating the loss separately

in the neutral conductor and in the loaded outside conductor. It is evident from what has been already said, that, if we calculated each conductor separately, our constant of 21.6 in the formula we just used would become 10.8, as the figure 21.6 was obtained by multiplying the constant 10.8 (= the resistance of a mil foot of wire) by 2 for the total length of wire of both legs of a two-wire circuit. Therefore, in this case,

$$e = \frac{I \times l \times 10.8}{A} \text{ volts.}$$

In this case the neutral conductor carries 50 amperes (the difference between the heavily loaded and lightly loaded conductors), and the heavily loaded outside conductor would carry 100 amperes. The loss would therefore be as follows: Loss in neutral conductors $= \frac{50 \times 300 \times 10.8}{216,000} = .75$ volts and in the loaded outside conductor $= \frac{100 \times 300 \times 10.8}{216,000} = 1.5$ and the drop of voltage in the lamps on the loaded side would be equal to the sum of these two losses, or 2.25 volts. The drop of voltage in the lamps for any other amount of unbalance, and also the drop on the lightly loaded side in this particular case, may be obtained in this manner. The remaining formulas given herein above, for two wire feeders, can be applied in precisely the same way by making these modifications.

Of course, a three-wire system should be well balanced for many other reasons, and on that account it is usually safe to make the calculations on that assumption.

From what has been said, it is evident that if the neutral conductor were made equal to the combined capacity of the two outside conductors, the loss in the lamps on one side fully loaded, the other side being entirely disconnected, would be $1\frac{1}{2}$ times the loss in the lamps in case the sides were equally balanced. (In this case the neutral would have to carry the total current.) In the above case, (example 7), if we had two outside conductors of 216,000 c.m., and a neutral of 432,000 c.m.. the loss in the lamps on one side fully loaded (the other side being out) would be $1\frac{1}{2}$ times $1\frac{1}{2}$ volts, or 2.25 volts. If the neutral were one half the size (108,000 c.m.) of the two outsides, the loss in the same case would be 4.5 volts. These statements can all be verified by making the calculation for each conductor separately, as explained above.

As a matter of fact, in general practice, in calculating three-wire feeders, it is usual to assume the load equally balanced and to use the formula

$$A = \frac{I \times L \times 21.6}{e} \text{ C.M.}$$

it being remembered that I is equal one half to the total load carried on the two sides of the system, or, in other words, the load on one side, $L =$ the distance one way and $e =$ loss in the outside conductors which is twice the loss in the lamps themselves.

CHAPTER X

ALTERNATING-CURRENT WIRING

OWING to the reversals in the direction of the flow of current, certain phenomena are produced in alternating currents which are absent in direct-current circuits. The most important of these phenomena are, viz.:

Self-Induction; Mutual Induction; Skin Effect; Capacity Effect.

The second and fourth effects are rarely present in interior wiring, but, as they might all occur under certain circumstances, a brief description of each might be profitable.

SELF-INDUCTION

When a circuit supplied with direct current is closed, the current usually rises in a very small part of a second from zero to its full value, and continues at that value until some change takes place in the circuit, or in the electromotive force applied to it. In the case of circuit supplied with alternating current, the conditions are changed, however, owing to the rapid changes in the direction and value of the impressed electromotive force. When any circuit containing a source of e.m.f. is closed, a magnetic field is created which surrounds the conductor. The strength of the field varies with the current value and the physical conditions of the circuit, i.e., the surrounding medium (whether air or iron, etc.), the shape of the circuit (whether it consists of straight conductors, or wound in a coil), etc. If the current is direct current, the field remains constant or changes with variations in the strength of the current. The magnetic effects produced by such changes in direct current are usually very slight, except in case of electro magnets, field windings, etc., in which the current flows through a coil around an iron core. In such instances as these, when the connection is broken, a more or less heavy inductive effect takes place. In the case of alternating currents, however, the direction as well as the strength of the current is continually changing. This continual change in the direction

and strength of the current produces a corresponding variation in the magnetic field surrounding the conductor or circuit. The effect of this change of magnetic field is to set up a counter e.m.f. which opposes the flow of the current. This e.m.f. is called the electromotive force of self-induction, and is proportional to the rate of change of the flux which is linked with the circuit. This electromotive of self-induction sometimes materially affects the calculation of wiring circuits even in interior wiring, and a method of calculating its effect on the size of conductors is described hereinafter.

Mutual Induction

By mutual induction is meant the effect caused by the change in the current strength in the conductors of one circuit upon an adjacent circuit. The phenomenon is similar to self-induction in its general action, but differs from it in that it is the action of one circuit upon another circuit, instead of the action between the conductors of the same circuit.

The effect of mutual induction is, however, negligible for ordinary conditions in interior wiring, and need not be and therefore will not be discussed further in this volume.

Skin Effect

By this effect is meant the phenomenon which takes place in a conductor through which an alternating current is flowing, due to the fact that the current tends to flow through the outer surface or shell of the conductor and does not utilize the full conductance of the wire. The effect is proportional to the frequency of the alternations and the size of the conductors. It is relatively small with low frequencies (that is, a frequency under 60 cycles per second), and with conductors of smaller sizes than 0000 B. & S. gage.

It acts in the same manner as an increase in the ohmic resistance, or, therefore, as a decrease in the size of conductor. The following table gives the factor to be used in multiplying the ohmic resistance to obtain the combined resistance and skin effect. The figures in the first and third columns give the product obtained by multiplying the size of the conductor in circular mils by the frequency (number of cycles per second) of the current. For example, if we wish to find the combined skin effect and ohmic resistance (at a frequency of 60 cycles per

second) of a conductor of No. 4/0 B. & S. gage (211,600 circular mils), we multiply the size of the conductor in circular mils by the frequency (211.600 × 60 = 12,696,000), and we find that for conductors of this size, at 60 cycles per second, the skin effect makes a difference of less than one half of one per cent and is therefore negligible for all ordinary cases. For conductors larger than 4/0 B. &. S., or for frequencies higher than 60 cycles per second, it would be wise to ascertain from the table whether the effect would be negligible or not.

Product of Circular Mils × Cycles Per Sec.	Factor	Product of Circular Mils + Cycles Per Sec.	Factor
10,000,000	1.00	70,000,000	1.13
20,000,000	1.01	80,000,000	1.17
30,000,000	1.03	90,000,000	1.20
40,000,000	1.05	100,000,000	1.25
50,000,000	1.08	125,000,000	1.34
60,000,000	1.10	150,000,000	1.43

The factors given in this table multiplied by the resistance to direct currents will give the resistance to alternating currents for copper conductors of circular cross-section.

Capacity

All circuits have a certain electrostatic capacity, inasmuch as each conductor acts like the plate of a condenser, and the insulating medium, whether it be air, gutta-percha, or rubber, acts as the dielectric. The capacity depends upon the kind of insulation, and it has been found that materials differ just as much in regard to their capacity effect as in their insulating value. As a rule, poor insulators have a low capacity, while good insulators have a high capacity, although there is not necessarily any connection between insulation and capacity. For a given insulating material, the capacity increases as the amount of surface of the conductors (which is proportional to their length and diameter), and inversely as the distance between the conductors.

The *charging current* required depends upon the capacity of the circuit, the frequency of alternations and the potential.

As a rule, the capacity of short secondary circuits is so very small that it need not ordinarily be considered in calculating such circuits. For this reason, we need not further discuss this effect here. For further information on the subject of the effect

of capacity on circuits. (See Alternating Current Wiring, by W. L. R. Emmet.)

From the foregoing it will be seen that while the effects of mutual induction, capacity and skin effect, rarely influence the size or arrangement of conductors in interior wiring, the action of self-induction will sometimes materially change the conductors for feeders and mains, and sometimes even for the branch circuits. For this reason it will be profitable at this juncture to define and describe some of the direct and indirect results of self-induction and to outline the methods to be used in calculating their influence on the size and arrangement of the conductors.

For the benefit of the reader who is unfamiliar with alternating currents, it may be stated that the counter electromotive force of self-induction is produced in almost the same manner in which the electromotive force in an armature coil of a dynamo is produced. The cause of both is due to lines of magnetic force being cut by a conductor. It is true that in the latter case the lines of magnetic force are stationary and the conductor moves so as to cut them, while in the former case the conductor is stationary and the lines of force move, but the idea is the same in both cases. In the case of a coil, for example, the current flowing through the conductor produces lines of magnetic force which cut the conductors of the coil and produce a difference of potential at the ends of the coil. If the current continued at a uniform value and in the same direction, this difference of potential would only be produced when the current was started or interrupted; if, however, the current is alternating and therefore changing continually, in direction as well as in value, the lines of magnetic force would be continually cutting the conductors first in one way (as the current rose to maximum value in one direction) and then in the opposite way (as it rose to a maximum value in the opposite direction).

One of the factors determining the calculation of the conductors is the medium that surrounds (or is in the immediate neighborhood of) the conductors. As has been already stated, the self-induction of an alternating-current circuit is materially effected when iron is introduced in a certain manner into the circuit. For example, if each conductor of a two-wire circuit, carrying an alternating current, were installed in a separate iron pipe, the self-induction of the circuit would be greatly increased

and would be much greater than if the circuits were run in the air, for the reason that the magnetic resistance would be decreased owing to the presence of the iron. If, however, the two conductors constituting the circuit were placed side by side in the same iron pipe the induction would be reduced to a minimum, for the reason that the effect of the current of one conductor would tend to offset the current in the opposite direction in the other conductor, and the resultant effect would be, under ordinary circumstances, negligible. For this reason it is necessary in all circuits carrying alternating current to avoid placing two or more conductors, constituting a given circuit, in *separate* iron or steel pipes. If the pipes were of brass, wood, or other non-magnetic materials, the conductors could be run in separate conduits. Several years ago a building in Pittsburg was wired for alternating current. The contractor either did not know of this effect or neglected to allow for it, and the conductors for the feeders and mains were installed in separate iron conduits. When the current supply was turned on, it was found that the inductive effect reduced the electromotive force to such an extent that the lamps instead of giving the full candle-power were barely red. It was necessary in this case to remove the feeders and mains, and to replace them so that the conductors of the same circuit were in the same conduit. While it is true, under certain conditions, that it would be possible to have an inductive effect in circuits in which the conductors were placed in the same conduit, yet, under ordinary conditions, in interior wiring, the effect would be so extremely slight as to be negligible.

The first cardinal point, therefore, to be observed in the use of alternating current is that, if iron or steel conduits are used, the conductors constituting a single circuit should be placed together in the same conduit or tube.

In aerial circuits (as, for example, in circuits where the conductors are run exposed on porcelain insulators or cleats), iron or other magnetic material are, under ordinary conditions, eliminated, yet the inductive effect, even in short lines, may become so great as to require careful calculation of the size and arrangement of the conductors. The conductors should be placed as close together as practicable in order to reduce the inductive effect. If the conductors constituting a given circuit are placed side by side, the magnetic field produced by one conductor tends to overcome the field produced by the other

conductor, and the inductive effect is minimized or overcome entirely.

We will now proceed to outline a method of calculating alternating-current circuit wiring where affected by self-induction. We will first consider single-phase circuits and later show what modifications must be made for polyphase circuits. One of the first elements to be considered in the calculation of alternating-current circuits is that of the power factor. What is power factor?

In practically all alternating-current measurements we have two phenomena, viz.: the real power and the apparent power. To express the ratio of these two, the term "power factor" has been introduced. Briefly defined, the Power Factor is *the "fraction by which we must multiply the apparent watts (i.e., the product of the electromotive force and amperes as measured by an ammeter and voltmeter) in order to obtain the real, or useful, watts."*

As already stated, one of the principal results of self-induction is the retarding effect upon the rise of the current. The amount of this retarding effect or "lag" of the current behind the impressed electromotive force depends, of course, upon the induction of the circuit, which, in turn, depends upon the amount and frequency of the current, the arrangement of the conductors, and upon the appliances supplied. The lag of the current behind the electromotive force is sometimes called difference in phase. As has just been stated, this lag varies with the appliances supplied, and is greater with motors than with incandescent lamps, inasmuch as in the former case we have coils of wire surrounding iron in the circuit and the self-induction is greater than in the case of incandescent or Nernst lamps, where no inductive coils are included.

Now this lag of the current materially affects the design of the circuits, and also the measurement of the power consumed, as we shall see as we proceed.

In direct-current circuits we know that the power in any circuit is measured in watts and is equivalent to the current in amperes multiplied by the electromotive force involts. In alternating-current work, however, this would only be true when the circuit contained no induction (which very rarely happens) and there was, consequently, no "lag," or difference, in phase between the current and electromotive force. A slight consideration of this statement should make this perfectly clear. If the

electromotive force and the current are not in phase, i.e., if the latter lags or hangs behind the other, it would be, obviously, wrong to multiply the current in amperes by the volts to obtain the watts consumed. Owing to the difference in phase between the two, they are not "pulling" together as the current lags behind the electromotive force; and, as they both change in direction as well as intensity, there are times when they are working in opposite directions, that is, the electromotive force is positive and the current is negative, or vice versa. In this case they are opposed to each other and the effective power, or the effective watts, is therefore equal to the product of the various instantaneous values of the current and the electromotive force when they are acting together, minus the product of the two when they are acting in opposite directions. As it is impossible, in practice, to obtain instantaneous values of the current and electromotive force when they are working together, and also when they are working in opposite directions, it is necessary to use a wattmeter which measures this effective power, or watts, instead of taking the product of the current and the pressure as measured by an ampere-meter and voltmeter.

In order to make this more clear, it will be wise to consider briefly the question of alternating-current measurements.

We know that the energy measured in watts in alternating current is equal to I^2R, which is equivalent to $E^2 \div R$. It will be seen from these equations that the power varies in proportion to the square of the current and to the square of the electromotive force. These facts must be borne in mind in the consideration of alternating-current measurements.

The value of the current in an alternating-current circuit is that value which would be equivalent to a direct-current producing the same amount of heating when applied to a given resistance. Inasmuch as the current changes both in value and direction, it is evident that an alternating-current instrument does not follow these changes, and the question naturally arises, What value does an alternating-current ammeter or voltmeter record? The answer is that they indicate the effective value which is known as the square root of the mean square. In less technical language, the square root of the mean square is equivalent to taking the value of the current at very small intervals, squaring these values, then taking the average of these squared

values and finally obtaining the square root of this mean value. It would appear, at first glance, that this result will be the same as though we merely took the average of the current measured at regular small intervals; but this is not true, for the reason that the square root of the average value squared is greater than the average value of the quantity itself, because the higher values of the quantity (that is, when the current is at a maximum in either direction), when squared, affect the resultant average much more than do the lower values. In fact, the average value of the current is actually 10 per cent less than the square root of the mean square value on this account, and, as has been stated, the energy varies as the square of the current, it is necessary therefore, to take a value which is proportional to the square of the current; hence we obtain the square root of the mean square. The value of the current(I), indicated by an alternating-current ammeter, is therefore equal to the square root of the square of the average values of the current.

As the power in an alternating circuit varies also as the square of the electromotive force, it could be shown, in a similar manner, that an alternating-current voltmeter indicates the square root of the mean square of the values of the electromotive force.

Having shown what values of the current or electromotive force are indicated by an alternating-current ampere-meter or voltmeter, let us now consider the question of power consumed in an alternating-current circuit.

As the actual or effective power is less than the product of the current and the electromotive force at any period of time, it is evident that the amount of the current is greater than the actual current required. The difference between the effective current and the apparent current is known as the "wattless" current. While this wattless current does not represent a corresponding amount of energy and does not require power in the engine serving to drive the dynamos supplying the said current, it does really exist and tends to heat the line conductors and the generator, and proper allowance must be made in the conductors and generators for the said current.

It is evident from the foregoing that in alternating current the power cannot be measured by merely taking the product of the current and electrical pressure as measured by an ammeter and voltmeter, as would be done in the case of direct currents. If the power be measured by using a voltmeter and ammeter, it

would be necessary to multiply the product of the two by the power factor in order to obtain the real power. In the design of circuits for alternating current, therefore, it is necessary to know or estimate a power factor for the load to be supplied. Where the load is incandescent lamps or similar non-inductive appliances, the proposition is relatively simple as the power factor is nearly unity. Where the load actually consists of motors or arc lamps, the power factor is less, and usually of variable quantity, depending upon the size of the motors, how nearly the motors, etc., are operating at their full rated load, and also upon their design. Generally speaking, the power factor of a load consisting entirely of incandescent or Nernst lamps is about 98 per cent; where the load is partly of incandescent lamps and partly of motors, a power factor from 80 per cent to 90 per cent may be assumed. Where the load is entirely of motors, the power factor may be 80 per cent or less, when the motors are operating at their full rated load; when the motors are operating at less than full load the power factor is often less than 80 per cent; the power factor of an arc lamp load is approximately 85 per cent. Wherever possible, it is best to obtain, as closely as possible, the estimated power factor from the manufacturer of the apparatus to be supplied, as there is considerable variation in the figures stated herein above. In figuring out the size of the conductors for a given load, it is necessary, therefore, to obtain the actual load and, having assumed a given power factor, divide the actual load by the power factor to obtain the apparent load in watts. This will give us the capacity required to be furnished by the generator or carried by the line conductors. If we divide the apparent load (in watts) by the impressed electromotive force, we will have the current which is carried by the conductors. Although the power actually used is equal to the actual watts, the conductors and generators must be amply large enough to carry the *apparent* current. This will be best understood by a practical example.

Suppose we have a load of motors which require, say, 200,000 watts delivered at their terminals at the potential of 200 volts. Assume that we know that these motors have a power factor of, approximately, .8; the actual watts required to be delivered by the generator and carried by the feeder would have to be 200,000 divided by $\frac{8}{10} = \frac{200,000}{.8} = 250,000$ watts. The generator

would have to be about 250 kw. capacity and the feeding conductors would have to be large enough to carry 1250 amperes $\frac{(250{,}000 \text{ watts})}{(200 \text{ volts})}$. This is an important point to be remembered in calculating the size of conductors and generators, because, while the power is not actually used, the current corresponding to the apparent watts heats the conductors and the generator and they must be sufficiently large to allow for this.

If the case just considered were direct current, the current required for the load just given would be 2000 watts divided by 200 volts, or 1000 amperes. As will be seen, this is 250 amperes less than in the alternating case we assumed. This 250 amperes represents the difference between the actual and the apparent watts, and is sometimes called the "wattless" current. Of course, as above stated, there is only one current actually flowing, and the term wattless current is merely used to represent the additional amount of current flowing in the conductors, due to the fact that the current and electromotive force are not acting in unison, owing to the self-induction of the circuit.

The writer knows of a case where a certain size generator was purchased for a factory installation. The installation was designed by a mechanical engineer who was unaware of this peculiarity of alternating current. The engineer figured up the actual watts required by the motors and estimated the maximum probable load, and purchased a generator of sufficient size to carry this load, making no allowance for the power factor of the motors. The result was that the generator was found to be too small and it was necessary to purchase an additional generator solely because the wattless current caused the generator to heat, although, of course, it did not affect the actual load on the engine.

CHAPTER XI

CALCULATION OF ALTERNATING CIRCUITS

FROM the discussion of alternating-current phenomena, we now that under certain conditions modifications must be nade in the methods used for calculating direct-current conuctors in the case of alternating-current circuits, even for lowotential circuits and for short distances. The two corrections hich usually have to be made in secondary and interior wiring re the correction for inductance and the correction for the ower factor. The first depends upon the frequency and the hysical condition of the circuit, and the second upon the charac- er of the load. We will now proceed to consider how calculations hould be made for alternating-current circuits.

Where the circuits are run in conduits having both wires in a ingle tube, and where they are so arranged that the distance etween the two conductors is an inch or less, the calculation nay be made in precisely the same manner as for direct-current ircuits so far as inductance is concerned. The effect of self-in- uction, under such conditions, would be so slight as to be egligible, for the reasons already given. Where, however, the con- uctors are run exposed and where they may be separated several nches, or even a foot or more, and particularly in the case of arge conductors, the effect of self-induction may be such as to ncrease considerably the drop of potential in the circuit.

As just stated, the power factor of a circuit depends upon the haracter of the load. In some instances, as, for example, in- andescent lamps, no correction need be made for the power actor, for the reasons already stated, the power factor for in- andescent lamps being practically unity. In the case of induc- ion motors, however, the load is quite inductive, and there is uite a lag of the current behind the electromotive force, and llowance for the power factor must be made in all such calcula- ions.

As already stated, the effect of power factor in the circuit is o increase the current, and the first step, therefore, in making

the alternating-current calculation, is to find the current that will be flowing in the circuit. To do this, we divide the power in watts by the power factor, and we get the apparent power in the circuit expressed in watts. If we divide this apparent power by the voltage, we obtain the current flowing in the circuit. If, for example, we had a load of motors amounting to 25,000 watts, and we knew that the power factor in this case would be approximately 80 per cent, and the voltage of the motors was 250 volts, we would proceed as follows to obtain the current in amperes:

$$\frac{25{,}000}{.8} = 31{,}250 \text{ watts.}$$

The current, therefore, at 250 volts would be

$$\frac{31{,}250}{250} = 125 \text{ amperes.}$$

In the same manner, we could obtain the current corresponding to any power factor. In making the calculation for power factor, the following figures may be taken when more exact data cannot be obtained. For incandescent and Nernst lamps load 98 per cent; for arc lamp load 85 per cent; for induction motors 80 per cent. It is obvious that for combined loads of lighting and of motors the power factor will be somewhere between the values given above, depending upon the relative amounts of lighting and power.

While it is perfectly possible to make the calculations for conductors for alternating-current circuits in somewhat the same manner as for direct-current circuits, a simple method is that described by Mr. Ralph D. Mershon in the *American Electrician* of June, 1897, and which is partly reproduced herein below.

Calculation of Drop. — Most of the matter heretofore published on the subject of drop treats only of the interrelation of the e.m.f's involved, and, so far as the writer knows, there have not appeared in convenient form the data necessary for accurately calculating this quantity. The table and chart include in a form suitable for the engineer's pocket-book everything necessary for calculating the drop of alternating-current lines.

The chart is simply an extension of the vector diagram, giving the relations of the e.m.f.'s of line, load, and generator. E is the generator e.m.f.; e the e.m.f., impressed upon the load; c that component of E which overcomes the back e.m.f. due to the impedance of the line. c is made

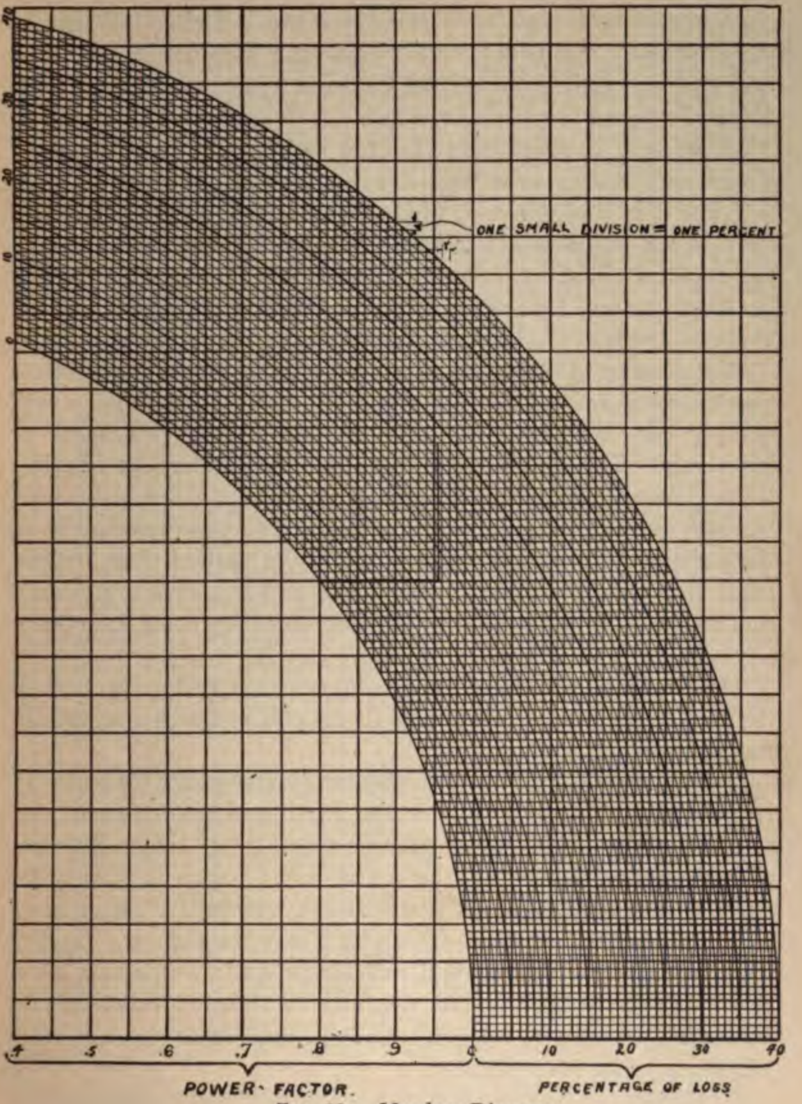


FIG. 68. — Mershon Diagram.

up of two components at right angles to each other. One is a. the component overcoming the IR or back e.m.f. due to resistance of the line. The other is b, the component overcoming the reactance e.m.f. or back e.m.f. due to the alternating field set up around the wire by the current in the wire. The drop in pres-

sure due to both resistance and reactance is the difference between E and e. It is d, the radial distance between two circular arcs, one of which is drawn with a radius e, and the other with a radius E.

The chart is made by striking a succession of circular arcs with 0 as a center. The radius of the smallest circle corresponds to e, the e. m.f. of the load, which is taken as 100 per cent. The radii of the succeeding circles increase by 1 per cent of that of the smallest circle, and, as the radius of the last or largest circle is 140 per cent of that of the smallest, the chart answers for drops up to 40 per cent of the e.m.f. delivered.

The terms resistance-volts, resistance e.m.f., and reactance-volts, reactance-e.m.f., refer, of course, to the voltages for overcoming the back e.m.f.'s due to resistance and reactance respectively. The figures given in the table under the heading "Resistance-Volts for One Ampere, etc," are simply the resistances of 2,000 feet of the various sizes of wire. The values given under the heading "Reactance-Volts, etc.," are, a part of them, calculated from tables published some time ago by Messrs. Houston and Kennelly. The remainder were obtained by using Maxwell's formula.

The explanation given in the table accompanying the chart is thought to be a sufficient guide to its use, but a few examples may be of value.

Polyphase Circuits. — A four-wire *quarter-phase* (two-phase) transmission may, so far as loss and regulation are concerned, be replaced by two single-phase circuits identical (as to size of wire, distance between wires, current and e.m.f.) with the two circuits of the quarter-phase transmission, provided that in both cases there is no inductive interaction between circuits. Therefore, to calculate a four-wire, quarter-phase transmission, compute the single-phase circuit required to transmit one half the power at the same voltage. The quarter-phase transmission will require two such circuits.

A three-wire, *three-phase* transmission, of which the conductors are symmetrically related, may, so far as loss and regulation are concerned, be replaced by two single-phase circuits having no inductive interaction, and identical with the three-phase line as to size, wire, and distance between wires. Therefore, to calculate a three-phase transmission, calculate a single-phase circuit to carry one half the load at the same voltage. The three-phase trans-

Table for Calculating the Drop in Alternating-Current Lines

By means of the table calculate the *Resistance-Volts* and the *Reactance-Volts* in the line, and find what per cent each is of the E.M.F. delivered at the end of the line. Starting from the point on the chart where the vertical line corresponding with power-factor of the load intersects the smallest circle, lay off in per cent the resistance E.M.F. horizontally and to the right; from the point thus obtained lay off upward in per cent the reactance-E.M.F. The circle on which the last point falls gives the drop in per cent of the E.M.F. delivered at the end of the line. Every tenth circle arc is marked with the per cent drop to which it corresponds.

Throughout the table the black figures give values for ONE MILE of line corresponding to those of the light figures for 1000 feet of line.

Light figures are REACTANCE-VOLTS in 1000 feet of Line (=2000 feet of Wire) for One Ampere at 7200 Alternations per Minute (60 Cycles per Second) for the distance given between Centers of Conductors.

Size of Wire—B. & S.	Light figures are Weight in Lbs. per 1000 feet Single Wire.	Light figures are *Resistance-Volts* in 1000 feet of Line (2000 feet of Wire) for One Ampere.	½″	1″	2″	3″	6″	9″	12″	18″	24″	30″	36″
0000	639	.098	.046	.079	.111	.130	.161	.180	.193	.212	.225	.235	.244
	3376	**.518**	**.243**	**.417**	**.586**	**.687**	**.850**	**.951**	**1.02**	**1.12**	**1.19**	**1.24**	**1.29**
000	507	.124	.052	.085	.116	.135	.167	.185	.199	.217	.230	.241	.249
	2677	**.653**	**.275**	**.449**	**.613**	**.713**	**.882**	**.977**	**1.05**	**1.15**	**1.22**	**1.27**	**1.32**
00	402	.156	.057	.090	.121	.140	.172	.190	.204	.222	.236	.246	.254
	2123	**.824**	**.301**	**.475**	**.639**	**.739**	**.908**	**1.00**	**1.08**	**1.17**	**1.25**	**1.30**	**1.34**
0	319	.197	.063	.095	.127	.145	.177	.196	.209	.228	.241	.251	.259
	1685	**1.04**	**.332**	**.502**	**.671**	**.766**	**.935**	**1.04**	**1.10**	**1.20**	**1.27**	**1.33**	**1.37**
1	253	.248	.068	.101	.132	.151	.183	.201	.214	.233	.246	.256	.265
	1335	**1.31**	**.359**	**.533**	**.687**	**.797**	**.966**	**1.06**	**1.13**	**1.23**	**1.30**	**1.35**	**1.40**
2	201	.313	.074	.106	.138	.156	.188	.206	.220	.238	.252	.262	.270
	1059	**1.65**	**.391**	**.560**	**.728**	**.824**	**.993**	**1.09**	**1.16**	**1.26**	**1.33**	**1.38**	**1.43**
3	159	.394	.079	.112	.143	.162	.193	.212	.225	.244	.257	.267	.275
	840	**2.08**	**.417**	**.591**	**.755**	**.856**	**1.02**	**1.12**	**1.19**	**1.29**	**1.36**	**1.41**	**1.45**
4	126	.497	.085	.117	.149	.167	.199	.217	.230	.249	.262	.272	.281
	666	**2.63**	**.449**	**.618**	**.787**	**.882**	**1.05**	**1.15**	**1.22**	**1.32**	**1.38**	**1.44**	**1.48**
5	100	.627	.090	.121	.154	.172	.204	.223	.236	.254	.268	.278	.286
	528	**3.31**	**.475**	**.639**	**.813**	**.908**	**1.08**	**1.18**	**1.25**	**1.34**	**1.42**	**1.47**	**1.51**
6	79	.791	.095	.127	.158	.178	.209	.228	.241	.260	.272	.283	.291
	419	**4.18**	**.502**	**.671**	**.834**	**.940**	**1.10**	**1.20**	**1.27**	**1.37**	**1.44**	**1.49**	**1.54**
7	63	.997	.101	.132	.164	.183	.214	.233	.246	.265	.278	.288	.296
	332	**5.27**	**.533**	**.697**	**.866**	**.966**	**1.13**	**1.23**	**1.30**	**1.40**	**1.47**	**1.52**	**1.56**
8	50	1.260	.106	.138	.169	.188	.220	.238	.252	.270	.284	.293	.302
	263	**6.64**	**.560**	**.729**	**.893**	**.993**	**1.16**	**1.26**	**1.33**	**1.43**	**1.50**	**1.55**	**1.60**

mission will require three wires of the size and distance between centers as obtained for the single-phase.

A three-wire, quarter-phase transmission may be calculated *exactly*, as regards loss, and *approximately* as regards drop, in the same way as for three-phase. It is possible to calculate exactly the drop, but this involves a more complicated method than the approximate one. The error by this approximate method is generally small. It is possible also to get a somewhat less drop and loss with the same copper by proportioning the cross-section of the middle and outside wires of a three-wire, quarter-phase circuit to the current, they carry, instead of using three wires of the same size. The advantage, of course, is not great, and it will not be considered here.

As the problems cited by Mr. Mershon are for long-distance transmission lines, we will give examples more suited for the conditions in this book.

Problem No. 1. — Load of 1200 50-watt lamps = 60,000 watts; power factor = 98 per cent; distance = 500 feet; voltage at end of feeder to be 120 volts; feeder to consist of two 600,000 c.m. cables run exposed and placed about 8 inches apart. Find the loss in volts.

First obtain the apparent load in watts by dividing the real load by the power factor (98 per cent) in this case. (The power factor, it must be remembered, being that fraction by which the apparent load in volt-amperes must be multiplied to obtain the real or useful load in watts; or vice versa, having the real load in watts, it is the fraction we must use to divide this load by in order to obtain the apparent load.)

$$\frac{60,000}{.98} \text{ watts} = 61,224 \text{ apparent watts.}$$

To obtain the current we divide the load in watts by the voltage (120).

$$\frac{61,224}{120} = 510.2 \text{ amperes.}$$

Referring to the table of Reactances and Resistances of N. W. Fisher, we find that the resistance-volt per ampere of a feeder 1000 feet long, i.e., 2,000 feet of conductor (this table being based on length of conductor, not length of line or feeder) for a cable of 600,000 c.m. would be .0345 resistance volts per ampere; as our distance is only 500 feet (or 1000 feet of conductor) it would

Table of Reactances

(Copyright 1906 by Standard Underground Cable Co.)

Size in B. & S. or C. M.	Diameter in Inches	r-Resist. per 2000 ft. of Wire at 68° F.	Reactance per 2000 ft. of Wire at a Frequency of 60 Cycles per Second = x. Distance between Centers of Conductors. In Inches: ½	1	2	4	8	In Feet: 1	2	4	8
10	.1019	1.994	.116	.148	.1803	.212	.244	.2626	.294	.326	.358
8	.1285	1.254	.107	.138	.1695	.202	.233	.2519	.284	.315	.347
6	.1620	.7888	.095	.127	.1589	.191	.222	.2412	.273	.305	.337
4	.2043	.4960	.085	.117	.1482	.180	.211	.2305	.262	.294	.326
***4**	**.2320**	**.4960**	**.078**	**.111**	**.1424**	**.174**	**.206**	**.2247**	**.257**	**.288**	**.320**
3	.260	.3934	.072	.105	.1372	.168	.199	.2195	.250	.282	.314
2	.292	.3120	.067	.099	.1318	.163	.194	.2142	.245	.277	.309
1	.328	.2474	.063	.095	.1264	.158	.190	.2088	.241	.273	.305
0	.373	.1962	.056	.089	.1205	.152	.184	.2029	.235	.267	.299
00	.418	.1556	.052	.084	.1153	.147	.179	.1977	.230	.262	.294
000	.470	.1234	.046	.078	.1099	.142	.173	.1923	.224	.255	.287
0,000	.528	.09786		.073	.1046	.136	.168	.1869	.219	.251	.283
300,000	**.630**	**.06902**		**.064**	**.0964**	**.128**	**.160**	**.1788**	**.210**	**.242**	**.274**
400,000	.728	.05178		.058	.0898	.122	.154	.1722	.205	.237	.269
500,000	.815	.04042		.053	.0846	.117	.148	.1670	.199	.231	.263
600,000	.893	.03452		.048	.0804	.112	.144	.1628	.195	.226	.258
700,000	.964	.02958		.045	.0769	.109	.141	.1593	.192	.223	.255
800,000	1.031	.02598			.0738	.106	.138	.1562	.188	.220	.252
900,000	1.093	.02300			.0711	.103	.135	.1535	.186	.218	.250
1,000,000	**1.152**	**.02070**			**.0687**	**.100**	**.132**	**.1511**	**.183**	**.215**	**.247**
1,250,000	1.289	.01657			.0635	.096	.127	.1459	.178	.211	.243
1,500,000	1.412	.01381			.0594	.092	.123	.1417	.174	.206	.238
1,750,000	1.526	.01183			.0558	.088	.120	.1382	.170	.202	.234
2,000,000	1.631	.01035			.0527	.085	.116	.1351	.167	.199	.231

A	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40
B	.0022	.0044	.0064	.0084	.0103	.0121	.0138	.0155
A	1.45	1.50	1.60	1.70	1.80	1.90	2.00	
B	.0171	.0186	.0216	.0244	.0270	.0295	.0319	

be one half of this. For a load of 510.2 amperes, the loss in volts due to resistance (resistance volts) would be .0345 (constant) $\times$ ½ (our distance being 500 feet or 1000 feet in length) $\times$ 510.2 $= 8.83$ resistance volts or 7.4 per cent of the volts to be delivered.

In similar manner we obtain from the column headed 8 inches of the table of Reactances, the constant .144 for 2000 feet of 600,000 c.m. cable for one ampere. As our distance is 500 feet or 1000 feet of conductor, and the load is 510.2 amperes, the re-

*This and all larger sizes are stranded.

actance volts of this feeder are .144 (constant) $\times \frac{1}{2}$ (our length of conductor being 1000 feet or 500 feet distance) $\times$ 510.2 amperes = 36.73 reactance volts, i.e., loss due to reactance or self-induction of line, which is equivalent to 30.6 per cent of the volts to be delivered.

We find, therefore, that we would have a loss due to resistance of 7.4 per cent and to reactance of 30.6 per cent of the volts to be delivered. To obtain the combined loss, we use Mr. Mershon's table in accordance with the instructions given at top of same.

Starting at the bottom of the chart, we find the vertical line corresponding to 98 per cent power factor; follow this line up vertically until it intersects the inner or smallest circle (marked 0). From this point of intersection lay off horizontally to the right the percentage loss due to resistance (7.4 per cent), and from this last point lay off vertically upward the percentage loss due to reactance (30.6). This point, in this case, is found to be on the curve corresponding to 17 per cent, which is the actual percentage loss due to both resistance and reactance in this case. This loss it must be remembered is the percentage loss of the e.m.f. delivered, or 17 per cent of 120 = 20.1 volts loss. It is evident that this loss is excessive, not only on account of the loss in power, but because such a loss would result in poor regulation at the lamps, as there would be too great variation between no load voltage at the lamps. One way to reduce the loss would be to split the feeder into two sets of conductors of 300,000 c.m. This would reduce the reactance volts because the constant for 300,000 c.m. conductor is only 160 for conductors 8 inches apart, and these conductors would only carry one half of the current, while the constant for the 600,000 c.m. wire is 144 and these conductors would carry the total current. Therefore, the reactance of four conductors of 300,000 c.m. each carrying $\frac{1}{2}$ the current ($\frac{510.2}{2}$ = 255.1), compared to two conductors of 600,000 c.m. carrying all the current, would be $\frac{160}{144} \times \frac{1}{2}$ = 55 per cent of the reactance loss. This would mean, in this case, that instead of having a reactance loss of 30.6 per cent, we would have a reactance loss of 30.6 $\times$ .55 = 16.83 per cent. On this basis, the total loss would be (using the chart as before) 12 per cent, which, while high, might be allowed under certain conditions.

Another and better way would be to place the conductors closer together. There would of course be no objection to this with such a low potential as 120 volts. If the conductors were

placed 2 inches between centers, instead of 8 inches, the constant for the reactance loss would be .0804 instead of .144, or only a little more than half. Of course, in practice, we would not often encounter a problem just like the one given, as the distance for low potentials are usually less, and the loads subdivided so as to make each feeder carry less than the case given. However, the problem was selected so as to emphasize the reactance loss and show how it might be modified. No benefit would result in this case by increasing the size of conductors, as this would only reduce the resistance loss (which compared to the reactance loss is small anyhow), while the reactance loss would only be changed slightly.

To quote Mr. Mershon: "The component of drop due to reactance is best diminished by subdividing the copper or by bringing the conductors close together. It is little affected by change in size of conductors."

Problem No. 2. — Feeder supplying load of 100 amperes for Nernst lamps; distance 100 feet; voltage at end of feeder 240 volts; feeder to consist of two 0000 conductors run close together in iron pipe conductors about 1 inch between centers; power factor of lamps and circuit about 98 per cent.

Referring to Mr. Mershon's table (which gives the constants up to 0000 B. &. S), we find the resistance volts for 0000 wire to be .098 for 1000 feet distance for each ampere; in this case we have 100 amperes divided by .98 (power factor) or 102 amperes; therefore, the resistance volts loss is .098 constant $\times \frac{1}{10}$ (100′ $= \frac{1}{10}$ of 1000) $\times$ 102 amperes = 1 volt, or $\frac{1}{240} = .42$ of 1 per cent. In the same manner we find under the column marked 1 inch of reactances the constant .079 per ampere, for a distance of 1000 feet. Therefore, in this case, we have

$$.079 \times \tfrac{1}{10} \left(\tfrac{1}{10} \text{ of } 1000 \text{ feet}\right) \times 102 \text{ amperes}$$
$$= .8059 = .33 \text{ of } 1 \text{ per cent.}$$

Now, referring to the chart and starting at the point where the vertical line corresponding to 98 per cent power factor intersects the inner circle, and laying off the percentage of resistance volts (1 per cent) to the right horizontally, and the percentage of reactance volts upward, we find that the continued loss is only 1 per cent, which means in a case like this that the reactance loss can be ignored entirely. This is principally due to the fact that the conductors are placed so close to each other that the

reactance is reduced to a minimum, and also due to the short distance of transmission.

Problem 3. — Load 50 H.P. 250-volt induction motor having (at full load) an efficiency of 85 per cent and a power factor of 90 per cent; motor circuit 600 feet long, to consist of two conductors of 300,000 c.m. run exposed and placed 4 inches apart. Find the loss in volts.

The first step is to obtain the load in amperes. To do this, the actual watts required by the motor must be derived. The motors being rated, of course, in brake H.P. (50), we divide 50 by the efficiency, in order to obtain the electrical H.P. required to produce 50 brake horse-power. Assuming an efficiency of 85 % we have

$$\frac{50}{.85} = 58.823 \text{ electrical H.P.}$$

This figure multiplied by 746 (watts per electrical H.P.) would give the actual load in watts or

$$58.823 \times 746 = 43{,}882 \text{ watts.}$$

Now this is the actual load; to obtain the apparent load we divide by the power factor, 90 % or:

$$\frac{43882}{.9} = 48{,}758 \text{ apparent watts.}$$

NOTE: To obtain in one operation the apparent watts required by a motor of given efficiency and given power factor, the following formula should be used:

$$\text{Watts} = \frac{MHP \times 746}{Ef \times F}$$

where M.H.P. = mechanical or brake H.P.
746 = watts in electrical horse-power.
Ef = efficiency.
F = power factor.

Substituting in the case just given, therefore, we would have watts = 50 × 746 divided by .85 × .9 = 48,758 apparent watts.

The apparent watts divided by the e.m.f. of the motor gives us the apparent load in amperes, or

$$\frac{48{,}758}{250} = 195 \text{ amperes.}$$

Now, referring to Mr. Fisher's table, it is found that the resistance loss for a feeder of 300,000 c.m. for a distance of 1000 feet (2000 feet of wire) is .069 per amperes. In this case, we have .069 (constant for a distance of 1000′) × .6 (600′ = .6 of 1000 feet) × 195 amperes = 8.07 resistance volts or 3.2 per cent resistance loss. Under column of 4 inches in reactance volts table we find the constant .128. Therefore, we have .128 (constant) × .6 (distance 500′ = .6 of 1000′) × 195 amperes = 14.98 reactance volts or 6 % reactance loss.

Referring to the chart and starting with the vertical line corresponding to 90 per cent power factor, and following this vertical line up to the inner circle and laying off horizontally the loss in per cent of resistance volts (3.21) and the percentage loss in reactance volts (6 per cent), vertically, we find the combined loss to be 5.9 per cent of the volts delivered. If we wish to obtain the loss in per cent of the generator e. m. f. at the point of origin of the feeder, it would be necessary to divide the per cent loss, by the sum of the per cent loss added to the percentage of the total e.m.f. at the point of starting, which at the generator would be of course the full amount or 100 per cent, *i.e.*, in this case, the per cent loss of generator e.m.f. $= \frac{5.9}{5.9 + 100} =$ 5.57 per cent.

NOTE: It should be remembered that the tables given are based on a frequency of 7200 alternations per minute or 60 cycles per second, which is practically the standard in this country, except for special conditions. For any other frequency the reactances in tables given should be multiplied by said frequency divided by 60 or $\frac{f}{60}$ (f being the proposed frequency).

As already stated, to calculate a three-wire three-phase circuit, make the computation for a single-phase circuit to carry one half the load at the same voltage. Three conductors of the size determined by this calculation should then be used for the three-phase circuit. Of course, the distance between the centers of the conductors should be the same as in the single-phase circuit to obtain the same percentage of loss in voltage. The power transmitted by this circuit with the same loss would, therefore, be twice as great as in the case of a single-phase two-wire circuit having the same size of conductors.

To calculate a four-wire two-phase circuit (a quarter-phase

circuit, as it is sometimes called), make the computation for a single-phase two-wire circuit for one half the load at the same voltage. Two circuits of two wires each, of the size determined, should then be provided for the two-phase circuit.

To calculate a three-wire, 110-volt, 220-volt single-phase circuit, which is often used for secondary wiring (transformers usually having provision for three-wire connection), use the voltage between the outside conductors, taking one half the total load (if the system is balanced), and make all three wires the same size. The drop in voltage obtained is the drop between outside conductors and is twice the drop to each individual lamp, as explained elsewhere in the case of three-wire direct-current circuits. The weight of copper required for a three-wire 110–220 volt circuit having all three conductors the same size is three eighths of the weight required in the case of a two-wire circuit using the same voltage of lamps, exactly as in the case of direct-current circuits.

CHAPTER XII

EXAMPLES

THE WIRING OF A THIRTY-TWO STORY BUILDING

THE wiring of the thirty-two-story Park Row building will be described in this chapter. This building is said to be the tallest building in the world. As will be seen from the plans, the building is irregular in shape, and consists of cellar, basement, twenty-five full stories and seven partial stories. Its approximate cubical capacity is about 3,000,000 cubic feet. The building is, of course, of fire-proof construction. The partition walls are of 4-in. terra-cotta blocks. The floor construction consists of the usual flat terra-cotta arches; the flooring is double and laid on 3-in. wooden sleepers resting on top of the beams. This leaves a space of 3 inches between the tops of the beams and the under side of the rough flooring; this space is utilized for running the conduits.

Figures 69, 70, and 71 show the wiring of characteristic floors. The floors from the second to the twenty-fifth, inclusive, are almost identical in every respect, and consequently the wiring of one of these floors will show the features of all of them. The wiring includes both power and lighting circuits. The power wiring is a considerable factor, as all of the ten elevators are driven by electric motors. There are also several large electric ventilating fan motors. The lighting-circuit work will be considered first.

LOCATION OF OUTLETS

The lighting in the hallway entrances in front of the elevators and over the booths or small stores in the halls on the first floor consists of single-receptacle lights arranged symmetrically, as shown, in the ceiling. These receptacle lights are placed in plaster rosettes which form part of the ceiling design. The lighting of the remaining or store portion of the first floor is purely general in character and is obtained almost entirely by means of chande-

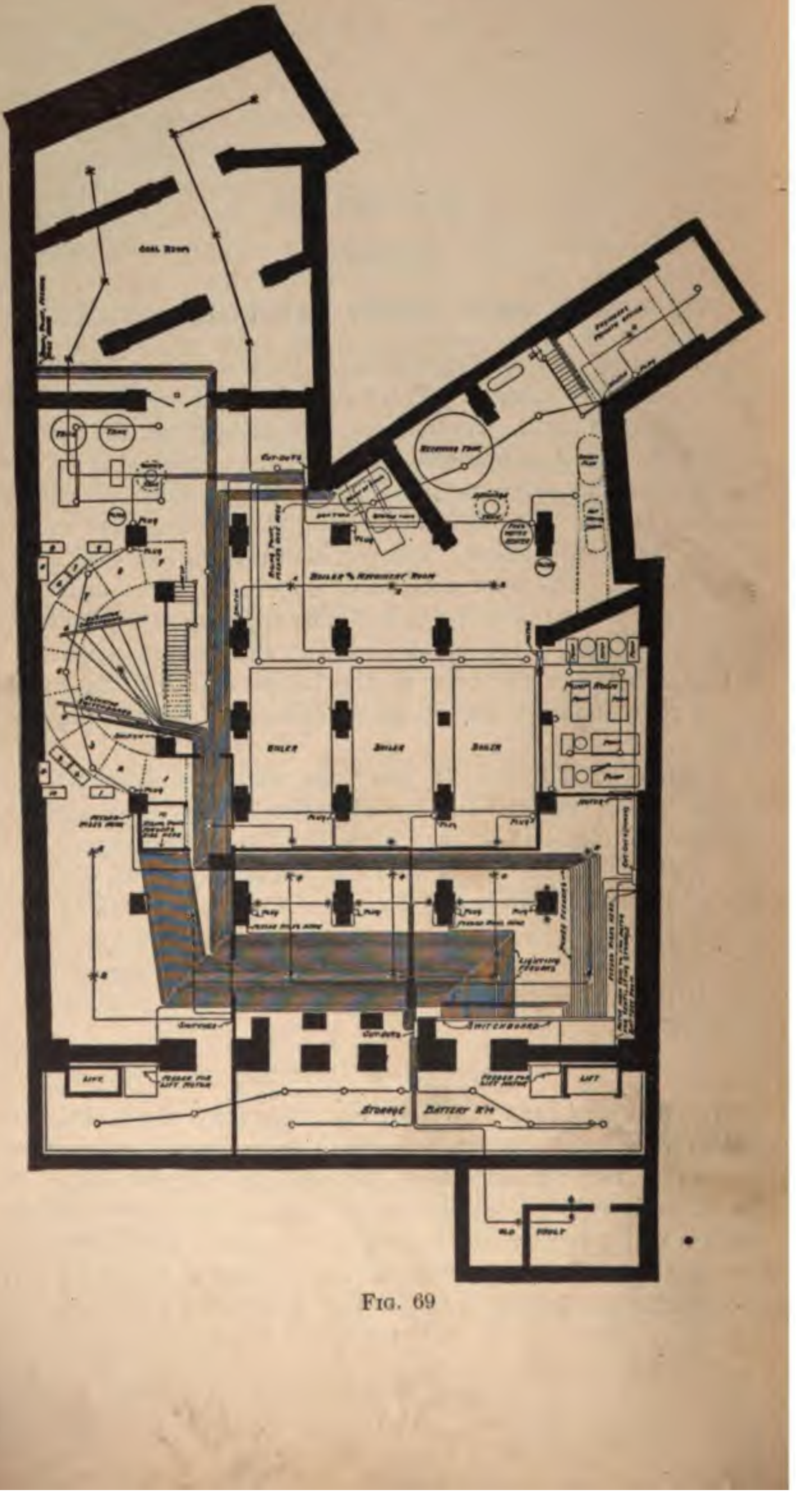

COAL ROOM
CUT-OUTS
BOILER & MACHINERY ROOM
BOILER
BOILER
BOILER
SWITCHBOARD
LIFT
LIFT
STORAGE BATTERY RM
OLD VAULT

FIG. 69

liers, as shown in Fig. 70. Means have been provided for window lights at the front end of the building. This consists of two cut-out panels placed under the two windows and supplied by special mains.

The arrangement of the outlets in the offices on the upper floors is practically the same at all floors and consists of a chandelier outlet and two side-bracket outlets in each office. The hall lighting is obtained entirely by means of ceiling lights. There are two chandelier outlets in the large toilet room and one in the small toilet room on each floor. A single ceiling light is provided in each of the passenger elevators. In the offices one 16-c.p. lamp is allowed for about 500 cu. ft. In the halls one 16-c.p. lamp has been allowed for every 600 cu. ft.

Branch Circuit Wiring

From the basement to the twenty-sixth story the lights serve two purposes, office lighting and hall or public lighting. There are no hall lights in the cellar or in the six upper stories. The lights in the cellar are wired on branch circuits originating at the two centers of distribution. Five centers of distribution serve to supply the branch circuits for the basement lighting. Four of these centers serve for the room or general lighting and one for the hall lighting.

At the first floor there are thirteen centers of distribution, seven of which serve for general lighting and six for hall lighting. These centers of distribution are located at six points, two or more of the distributing boards being usually placed in the same cabinet. Thus, at one point there are two groups of cut-outs for the halls and two for the offices. Each group is supplied and controlled separately, as is explained hereinafter under the head of Feeding System. As will be seen from Fig. 70, each branch circuit supplies not less than four nor more than eight lights. All of the ceiling outlets are controlled by switches placed on the wall, in the case of the room lighting, and in the cabinet containing the various cut-outs, in the case of the hall lights. It will be noticed that the hall lights are wired alternately, one half of a group or row being connected to one branch circuit, the other half or group being connected to a second circuit. These branch circuits in turn are divided between the two sets of hall-lighting centers of distribution. The two chandeliers at the main entrance are supplied by two circuits, one of

which supplies four lights at each chandelier, the other circuit supplying the remaining lights.

At the upper or office floors the arrangement of the branch circuits is very simple. The chandeliers and bracket fixtures are wired throughout on separate circuits, as shown in Fig. 71. None of the lights in the offices are controlled by switches, the lamps being turned on and off by the key sockets at the fixtures. The number of lights wired to one branch circuit varies from five to nine. The outlets in the halls are wired in alternation, so that every other fixture is connected to one set of distributing centers and the remainder are connected to the second set. Each circuit is controlled by a push-button switch at the distributing center at which said circuit originates. The bracket outlets on the landings of the stairs are fed by vertical circuits, originating at every fifth floor. Thus, a circuit starting at the second floor supplies the outlet on the stairs at that floor, and, rising vertically, supplies the outlets at the same point on the third, fourth, fifth, and sixth floors, inclusive. Separate circuits are run for the outlets in the two toilet rooms. Each of these circuits is controlled by a switch located at the center of distribution. These circuits are connected to the room or office lighting system, as it sometimes occurs that the lights are needed when the hall lights are not required.

An attachment plug is located at every floor in each of the two shafts back of the elevators. These attachment plugs serve for obtaining a movable light (by means of a flexible-cord connection) for the purpose of examining the elevator machinery. These plugs are wired on vertical branch circuits in the same manner as the outlets on the staircase landings. Each of the lights in the elevator cars is wired on a separate branch circuit, so that in case of trouble on any one of the elevator cables the light in the corresponding car would alone be affected. The elevator lights are controlled each by a rotating snap switch in the car itself.

Owing to lack of space, the wiring of the five upper (partial) stories is not shown. The wiring of the lights on these floors, however, follows the same general lines as those on the other floors.

Separate and distinct feeders are provided for the office lights and for the hall lights. In order to give the engineer complete control of the hall lights, two sets of feeders are provided for

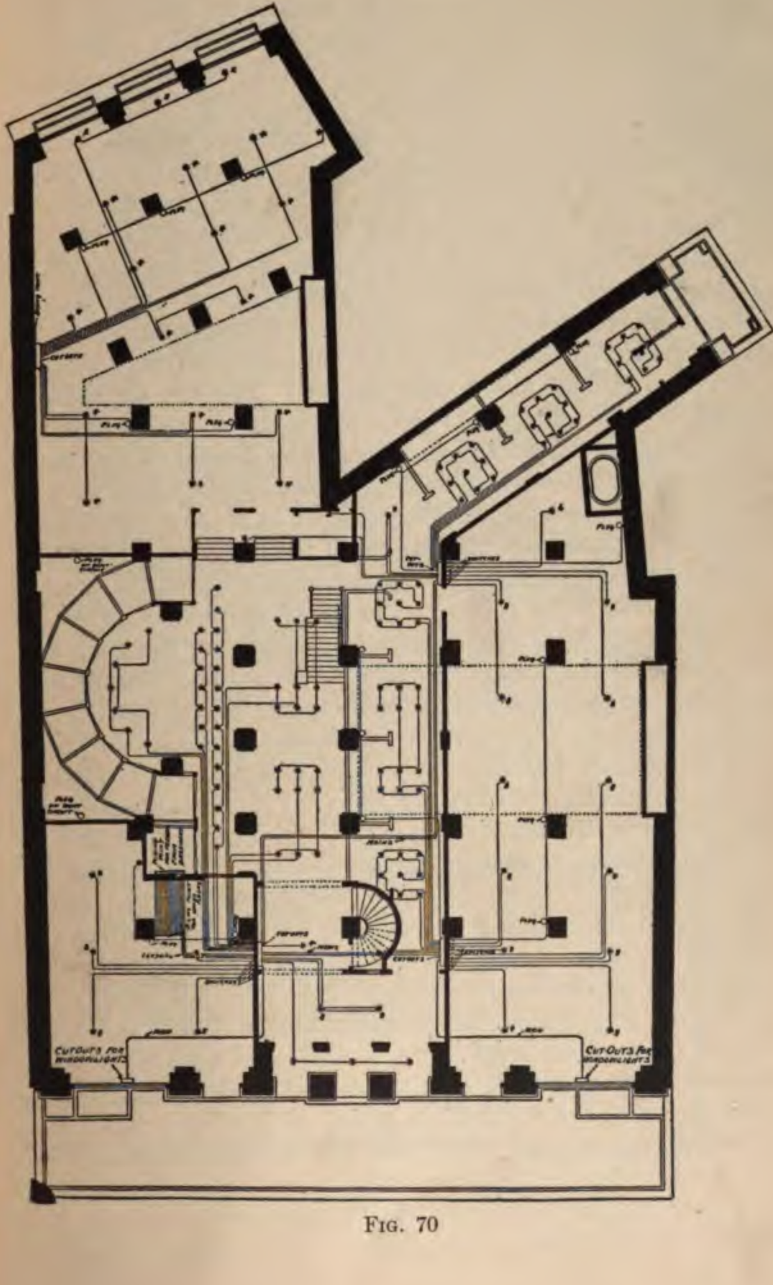


FIG. 70

them. It frequently happens that on dark days the sunlight coming from the offices through the glass in the doors and transoms is not sufficient to light the halls properly and it is necessary to throw on part of the hall lights. This is most readily done in the manner described hereinafter.

Figure 72 shows the general arrangement of the feeders, mains, and the distributing centers. In this figure the distributing centers are designated by circles having the letter H, O, or P inscribed inside the circle. These letters indicate that the distributing center serves to supply circuits for hall lighting, office, or other general lighting, and for power purposes, respectively. Two or more circles representing distributing centers, shown close together, indicate that the cut-out panels serving for these centers are located in the same cabinet. The two distributing centers in the cellar are supplied by a feeder which connects with one of the centers and is prolonged by a main to the second center. All the floors above the cellar are supplied by a vertical system of feeders and sub-feeders; that is to say, the feeders extend to certain floors at which they terminate and thence are prolonged to sub-feeders which supply distributing centers located at or near the same points at the floors above and below the feeding point. Thus the distributing centers at the basement and first floors and part of those on the second floor are supplied by feeders extending to and terminating at the first floor.

From the second to the twenty-fifth floor, inclusive, the building is divided into five electrical sections, designated by the letters A, B, C, D, and E. (See Figs. 71 and 72.) At each of these sections there is a distributing center serving for the branch circuits for office lighting. There are centers serving for the hall lighting circuits at three of these points only (sections A, C, and E), as the number and arrangement of the hall circuits did not make it necessary to have a center at each of the five points. There are rising points for the feeders at three of the five sections for office lighting but at only one of the sections for hall lighting. (One of these rising points serves for a double set of feeders.) It will also be seen from Fig. 72 that the second to the twenty-fourth floors, inclusive, are divided into groups of five floors each. For example, the floors from the twelfth to the sixteenth floor, inclusive, are supplied by feeders terminating at the fourteenth floor. In similar manner the fourth, ninth, nineteenth, and twenty-fourth floors are feeding floors, and the centers at the two floors

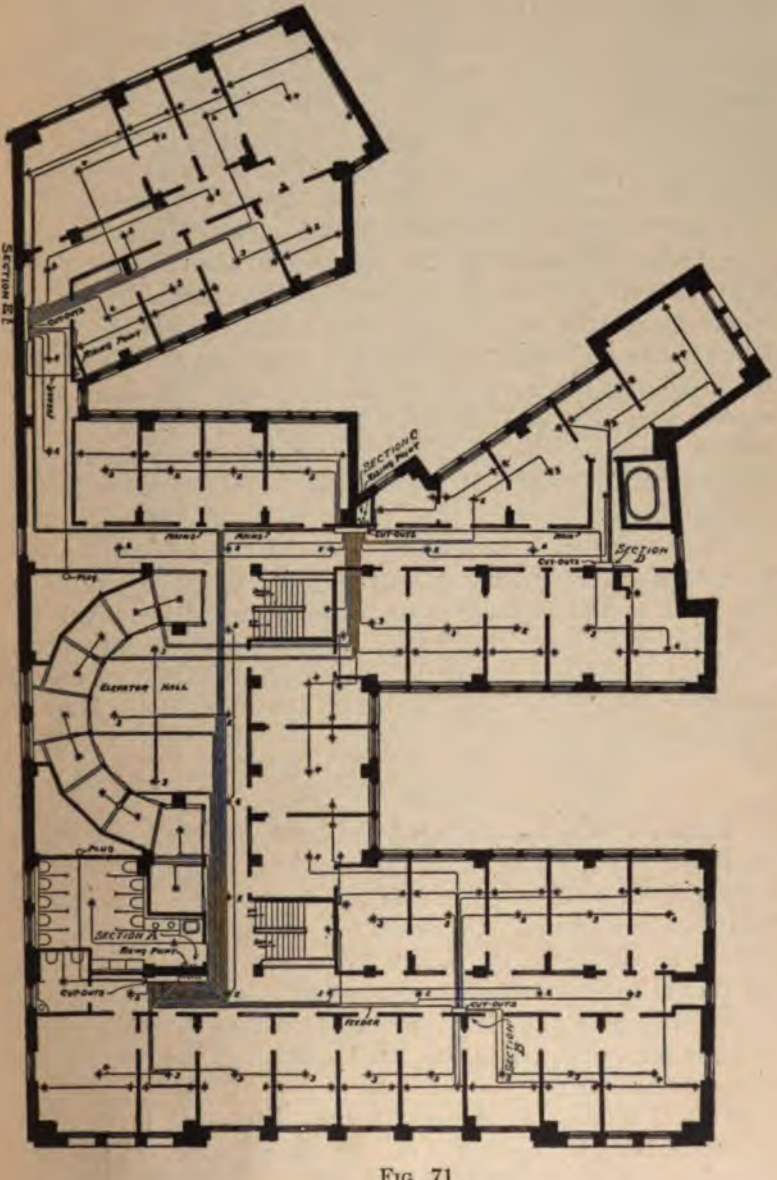

SECTION E
CUT-OUTS
RISING POINT
SECTION C
RISING POINT
MAINS
CUT-OUTS
SECTION B
PLUG
ELEVATOR HALL
SECTION A
RISING POINT
FEEDER
CUT-OUTS

FIG. 71

above and below these stories are supplied by sub-feeders forming prolongations of the main feeders.

As stated above, the feeders for the hall lights rise at one point only (section A), because the number of the hall lights did not warrant running a separate set of feeders for each set of the hall centers. Thus, at the twelfth floor, the two feeders for the two sets of hall lights terminate at the centers at section A. From this point vertical sub-feeders extend to the corresponding hall centers at the two floors above and below. From this point also, horizontal sub-feeders are extended to the centers for hall lights at sections C and E; these in turn are extended by vertical sub-feeders to the centers at the same relative points at the two floors above and below. The feeders supplying the centers for office lighting rise at three points at or near the distributing centers at sections A, C, and E. The centers for office lights at section D are supplied by horizontal sub-feeders (at the feeding floors) from the centers at section C in a similar manner to the hall-lighting system.

The twenty-sixth floor being a partial story, there are but four distributing centers for lighting purposes. The centers in the tower stories (twenty-seven to thirty-second inclusive) are supplied by a feeder terminating at the twenty-seventh floor. A second feeder terminating at the twenty-seventh floor serves to supply circuits for outside lights on the dome, at the level of the thirty-first floor.

Rising Points

There are three main rising points for the feeders located near sections A, C, and E, as shown in Fig. 71. The rising point in section A, in addition to serving for the feeders supplying the centers in this section, also serves for the feeders supplying the centers in section B, the feeders being run horizontally across the floor at each of the feeding floors, from this point to section B. These rising points consists of chaces built into the walls of the building for the purpose, with the exception of the rising point in the elevator shaft.

As will be seen from Fig. 69, the feeders run in conduits across the cellar ceiling to the various rising points. At the foot of each rising point a junction or pull box was provided in order to "break" the run of feeder into two sections, so as to facilitate pulling the feeder conductors into the conduits. The conduits

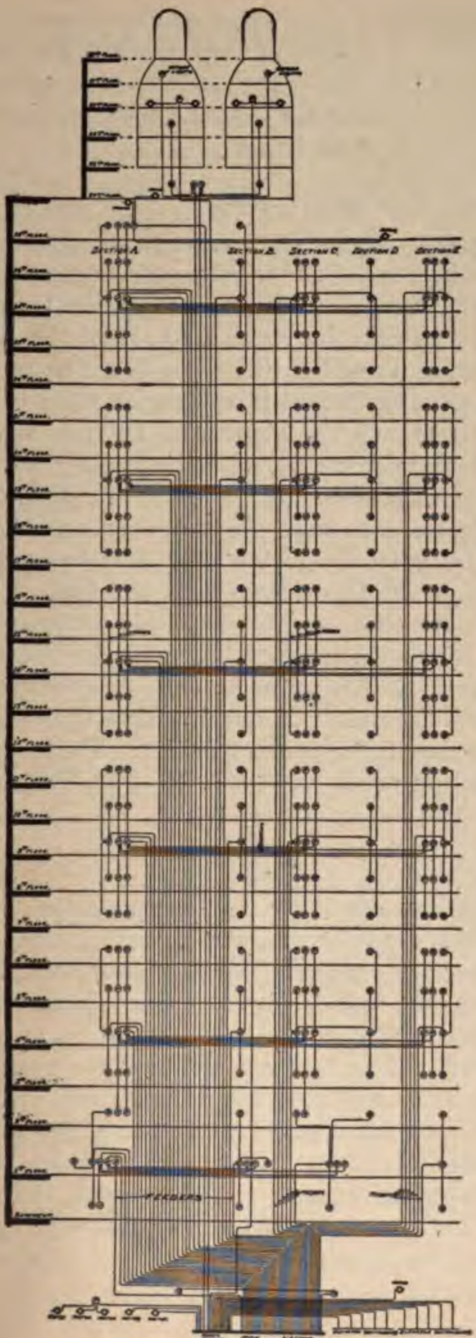


Fig. 72

are supported by iron clamps resting on angle irons located at every other floor, thus relieving the strain which would otherwise be placed on the couplings of the conduit. The feeder conductors in every case are securely fastened and supported at both ends of the vertical portion of the feeder.

Power Feeders and Circuits

Electric power is used for two purposes, viz., driving ventilating fan blowers and for the ten electric elevators. The elevators are of the Sprague multiple sheave screw type, the screws being placed vertically in the shafts back of the elevators and the motors being located on the cellar floor. A separate feeder is run from the switchboard in the engine room to each of the ten elevator motors. The controllers for the elevator motor are mounted (in two groups) on two supsidiary elevator switchs boards located in the cellar at the foot of the elevator shaft.

There are thirteen motors serving the ventilating blowers, six of these being located in the cellar, two on the twenty-sixth floor, one on the twenty-seventh floor, and four on the thirtieth floor. These thirteen motors are supplied by seven power feeders, the number of motors supplied by one feeder being determined by their size and their relative location. The feeders and circuits for the motors are run in conduit in precisely the same manner as those serving for lighting purposes. The conduits, wires, outlet boxes, and panels are similar to those described elsewhere in this book.

Plant

The plant consists of four units aggregating 575 kilowatts capacity. The dynamos are direct-current, compound-wound, 116-volt machines, and are direct-connected to a high-speed compound non-condensing engines. The dynamo plant is supplemented and balanced by a storage battery of 2500 ampere-hours capacity. Two boosters are used for charging and for maintaining and equalizing the voltage; one is engine-driven and is of 40-kilowatts capacity, the other is motor-driven and is of 20-kilowatts capacity.

The switchboard consists of three panels, the middle panel serving for the generators and storage battery, the right-hand panel serving for lighting feeders, and the left-hand panel for power feeders.

THE WIRING OF A LARGE HOTEL

So far as the electric wiring is concerned, a hotel may be considered as being divided into three distinct portions; namely, the working or service portion, the public portion, and the apartment or bedroom portion. The first usually includes the basement and cellar floors, the second includes the ground or first floor, and the third the apartment or bedroom floors. (On account of space limitations characteristic floor plans of the latter two portions only will be shown.)

The service or working portion of the hotel usually includes the kitchen, serving-rooms, storage space, machinery, etc. The lighting of these portions is relatively simple. The lighting of the kitchen and serving-rooms is, in the majority of cases, most effectively and economically accomplished by means of ceiling outlets. If ceiling outlets are used they should be controlled by local push-button switches, as the fixtures usually have short stems and the key sockets at the lamps are therefore quite out of reach. Special receptacle outlets should be placed under the hood, over the kitchen ranges. The engine, boiler, pump, and other machinery rooms are generally best lighted by means of drop cord and wall socket outlets, placed with special reference to the machine, or portion thereof, to be lighted.

The lighting of the second (public) portion of the hotel should for obvious reasons be more or less decorative in effect, and on a larger and more splendid scale than the rest of the house. It is therefore necessary not only to provide a large number of lights on these floors, but to obtain a suitable grouping and arrangement of the lights themselves. To this end a conference between the architect and the electrical engineer should be held for the purpose of fully discussing the question of lighting.

The restaurant is usually lighted by ceiling and bracket fixtures. In some cases individual lights on the tables are used, but this is rarely the case, owing to the difficulty of getting wires to the tables. Where it is possible to decide beforehand on exactly what points the tables will be located, the current supply can be carried to the table lights by means of floor outlets; but even this arrangement is objectionable as it either requires that a hole be made in the tablecloth, or else that a flexible cord be used to make the connection to the lamp on the table. It is usually impossible, however, to locate the tables beforehand, and

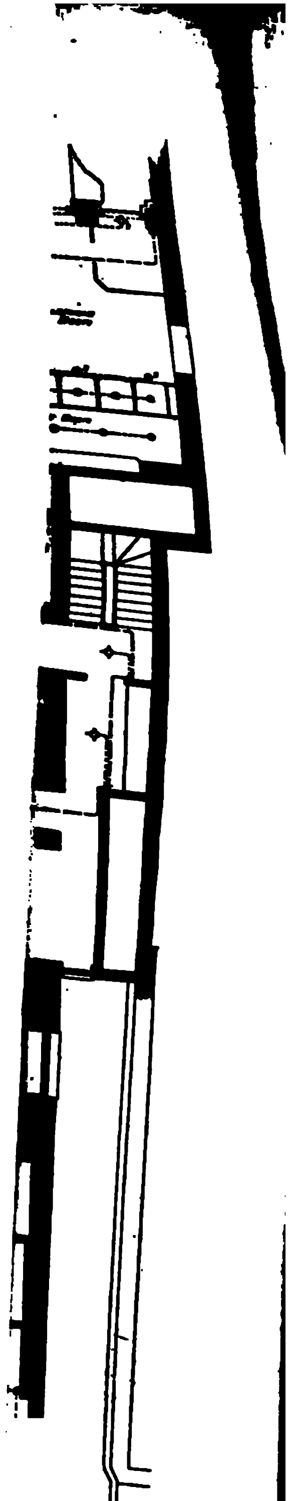
it is rarely attempted. Of course, base plug outlets may be used for connecting with tables placed against or near the walls, but, as a rule, table lighting in a restaurant is probably best accomplished by means of candles.

The lighting of the café, palm garden, and other rooms of similar character is usually less conventional than that of the restaurant, for the reason that the architectural treatment of these rooms is generally quite different from the restaurant.

The lights in the restaurant and café should be controlled at a point either inside or just outside the room in which the lights are located. These switches should preferably be placed in the cut-out cabinet at which the branch circuits originate. The lights in the entrance corridor, etc., should generally be controlled at the hotel office.

Coming to the third (apartment) portion of the hotel, the first point to be decided upon is the number of lights to be allowed for an average-sized bedroom. If it be necessary to keep the number of lights down to the lowest limits, ceiling outlets should be dispensed with and two single side-bracket outlets provided, one located on each side of the bureau or dressing table. If the scheme of lighting is on a more elaborate scale, a ceiling outlet or base plug outlet for a reading light may be added, and in some cases both may be provided. Each of the rooms at the Waldorf-Astoria Hotel was provided with two wall lights (one on each side of the bureau), a ceiling outlet and a base plug near the bed for a reading light. The number of lights in the ceiling fixture varied, of course, with the size of the room. The ceiling lights were controlled by two switches placed near the door, one switch controlling a single light (called the "night light") and the other switch controlling the remaining ceiling lights. The side bracket and reading lights were controlled by the key sockets only. A light was also provided in each bedroom closet. This closet light was controlled by a push-button (not a door automatic) switch placed just inside the closet door.

In locating the side lights and base plug outlets in the bedrooms, it is essential first to lay out the furniture in the rooms so as to have the outlets come in the proper places. This can most easily be done by making paper templates of the bed and bureaus, on the same scale as the plans, and then arranging these on the plans in the best positions. The lights can then be located to suit the particular arrangement in each case. The arranging



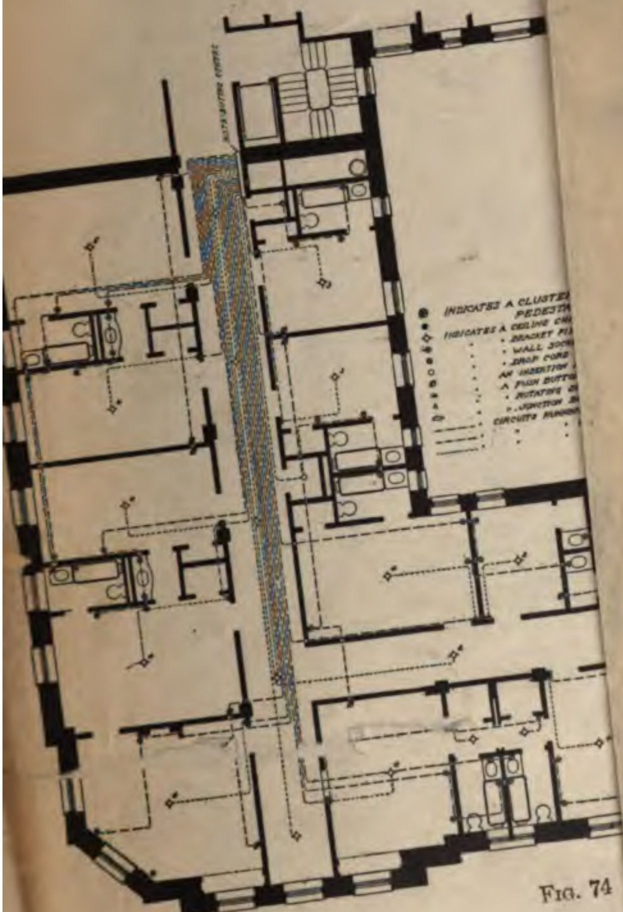


FIG. 74

of the furniture on the plan should, of course, be done by the architect, or with his assistance and under his supervision.

For the purpose of illustration the writer has selected, as a typical example of electric light wiring in a large hotel, the new Forty-third Street extension of the Manhattan Hotel, New York City. As stated before, only two typical floors are shown. Fig. 73 shows the wiring of the ground floor, and Fig. 74 shows the characteristic features of the upper (bedroom) floors. The current supply is direct current at 116 volts pressure, and is derived from the generating plant in the cellar.

Ground Floor

Figure 73 shows the Forty-third Street end of the ground floor and includes the restaurant, garden court, office, entrance, waiting-

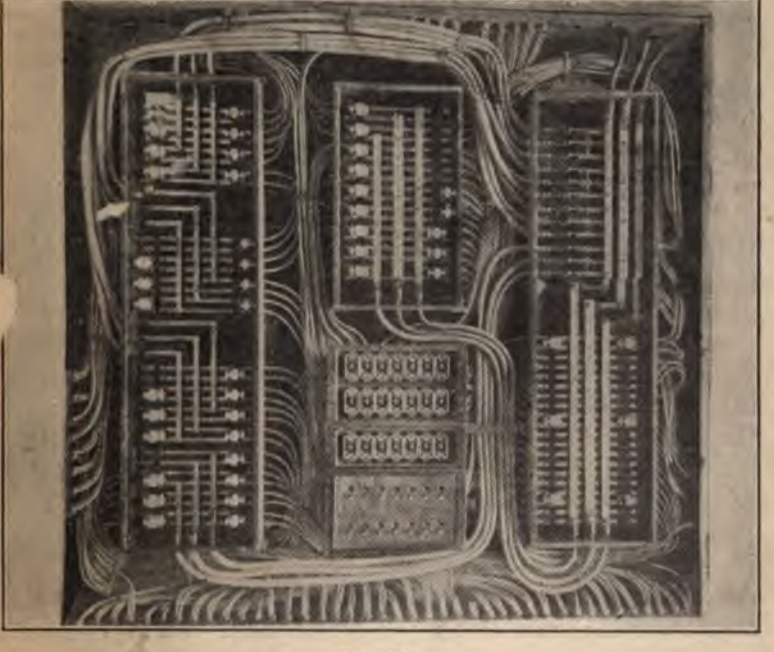


Fig. 75

rooms, and corridors, etc. The lights on this floor are supplied from three enters of distribution located where shown on the plan. Fig. . is from a photograph of the distributing center located in the serving-room of this floor. The photograph was

taken by the writer before the doors and trim were placed in position on the cut-out cabinet, and shows the panel-boards, switches, fuse-holders, connections, etc. (This type of fuse is no longer used or approved, but otherwise the panel is of an approved kind.) It is possible to trace in this figure the various connections between the main panel-boards at the left side and the lower portion of the center, and the subsidiary groups of cut-outs at the right side. The latter four groups of cut-outs serve to protect the lights in the garden court; the circuits are controlled by knife switches located on the main left-hand panel. The lights on the ground floor are (except where local switches are shown) all controlled by switches located at the three distributing centers. The circuit lines, outlets, switches, etc., are shown diagrammatically in both Figs. 73 and 74. The explanation of the symbols is given in Fig. 74.

Restaurant

Each of the four ceiling lights in the restaurant is supplied by four branch circuits originating at the center of distribution in the serving-room. The side bracket fixtures are (with two exceptions) supplied in pairs, by branch circuits also originating at this center. Each of the branch circuits supplying lights in the restaurant is controlled by a push-button switch located in the cut-out cabinet.

Garden Court

The garden court is lighted by two separate groups of individual lights. The first group forms a rectangle along the sides of the ceiling and consists of 102 receptacle lights placed in plaster rosettes specially designed for the purpose. Only the lamps themselves are visible from below, although the outlet boxes and connections are accessible by removing a small metal canopy covering the orifice of the outlet box. The lamps are wired in alternation, and are supplied by 14 branch circuits originating at the serving-room centers of distribution. These lights are controlled in two groups by knife switches located at that cut-out cabinet. (See Fig. 75.) One group consists of 53 lights, the other of 49 lights. The second main group of lights in the garden court consists of 100 receptacle lights placed above the circular stained-glass ceiling or skylight. These lights serve the double purpose of supplying general light in the garden court and to

illuminate the stained-glass ceiling or dome. The outlets themselves are accessible from above the glass ceiling. The lights are wired in alternation and are supplied by 14 branch circuits originating and controlled at the serving-room distributing center. The lights are controlled by knife switches at that point, in two groups of 50 lights each.

Corridor

The lights at each of the ceiling outlets in the corridors are supplied by two separate branch circuits; each branch circuit supplies lights at two or more outlets and is controlled by a push-button switch located at the center of distribution at which the circuit originates. This makes it possible to have all or part of the lights at these outlets turned on, as may be required.

Office

The office is lighted partly by bracket outlets located on the columns and partly by outlets placed on the marble railing at the rear of the office. Plug outlets have also been provided for making connections to desk outlets.

Outside Lights

The outside lighting is provided for by a group of receptacle outlets over the main entrance, and pedestal fixture outlets located above the railing along the front and sides of the hotel. The 50 receptacle outlets are located in an iron canopy over the main entrance. They are supplied by branch circuits originating in the basement, but are controlled (through mains) by two knife switches located at the distributing center in the corridor at the ground floor. (See also Fig. 76.) The outside standard outlets (marked P in Fig. 73) consist of 12 lights each and are supplied by 13 separate branch circuits originating at a distributing center in the basement. The entire group is controlled by a knife switch at that point. Each circuit runs along the basement ceiling to a junction box placed under the corresponding pedestal fixture on the sidewalk; thence the circuit rises in conduit through the stone coping and up through the iron pedestal itself to the fixture at the top of the pedestal.

The coat room and telephone booths are lighted by drop-cord outlets, as shown. The lavatory in the ladies' waiting-room is lighted by a single receptacle outlet placed on the partition

between the closets. The conduit for this outlet runs to a junction box located in the wall at the level of the top of the partition; from this box the conduit runs along the top of the partition to the special receptacle on the partition.

Upper Floors

There are two distributing centers at each of the upper (bedroom) floors, at which the branch circuits for these floors originate. Each of the bedrooms is lighted by a ceiling outlet, two side wall (bureau) outlets and a base plug outlet near the bed, for serving a reading light. The ceiling lights are controlled in one group by a push-button switch placed near the door. The bracket and plug outlets are not controlled by switches other than the key lamp sockets on the fixtures. The bath-rooms are lighted by side bracket outlets placed beside the wash basins. In the larger rooms the extra wash-rooms between the bath-rooms and the closets are lighted by side bracket lights placed on each side of the basin, as shown. The bath-rooms attached to the larger outside rooms are also provided with plug outlets serving for connection for curling-iron heaters, milk warmers, etc. The ceiling outlets in the corridor are wired in alternation so that every other outlet may be lighted, in case all the lights are not needed. The switches for the corridor lights are located at the distributing center at which the circuits originate.

Feeder System

As will be seen from the diagram, Fig. 76, the cellar, basement, and ground floors are supplied by separate feeders. This is done because of the great importance of having continuous and uninterrupted lighting service at these floors. The three distributing centers at the cellar are supplied by a single feeder which terminates at one of the centers and supplies the other two by means of mains extended from the feeder. Three of the eight distributing centers at the basement floor serve to supply the outside lights, as described above. The distributing center for the outside street lamps is supplied by a separate feeder from the main switchboard. The centers for the receptacle lights over the entrance are supplied by mains from the distributing center in the corridor at the ground floor. The other five distributing centers at the basement floor serve for the basement lights only; they are fed by two separate feeders, one of which serves two

centers and the other three centers, as shown. Each of the three centers at the ground floor is supplied by a separate feeder.

The upper floors, from the first to the fourteenth inclusive, are divided into two symmetrical sections. Each section has its own

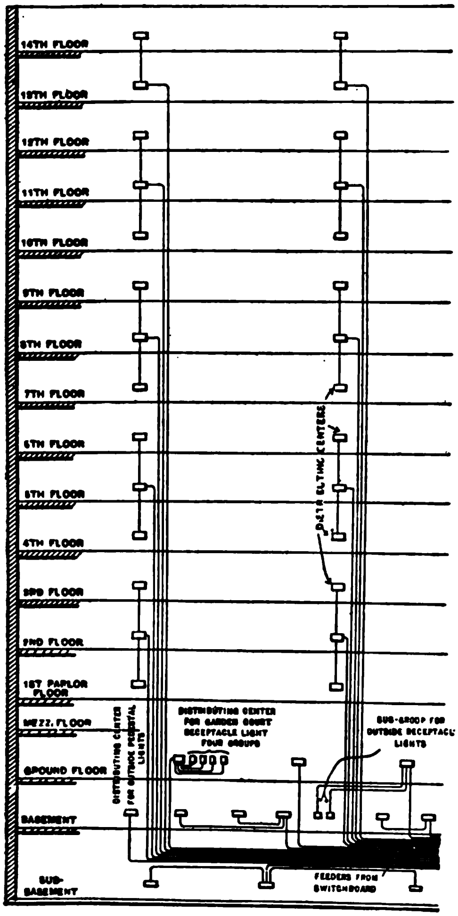


Fig. 76

distributing center, and its own set of supply feeders. The distributing center in each set is located at the same point at each floor. Each feeder from the first to the twelfth floor inclusive serves to supply three distributing centers. The feeder terminates at the middle center of a group of three, and is extended by mains to the corresponding centers at the floors immediately

above and below. In the case of the thirteenth and fourteenth floors, the feeders terminate at the thirteenth floor and are extended by mains to the corresponding centers at the fourteenth floor.

WIRING OF A LARGE PRIVATE RESIDENCE, N. Y. CITY

The building is a fire-proof construction and consists of a cellar, basement, and six stories. The construction is of the skeleton type, having iron girders and beams with terra-cotta arches and terra-cotta partitions. The flooring above the basement is of wood except in bath-rooms, kitchens, etc., where it is of tile. The distance between the top of the beams and the finished floor is five inches.

The electric current supply for the building is derived from the street mains of the New York Edison Company, and is three-wire for lighting, and two-wire for power, the lamps used being 120 volts and the motors 240 volts.

The plans of the cellar are not shown as the lighting on this floor is not of sufficient interest to require description. The street mains enter the buidling at the front of the house, at basement floor, where a service switch and cut-out is installed; thence they extend to the house feeder switchboard located at the rear of the cellar. At this point, the meters for lighting and power are located; various feeders for both lighting and power also originate at this board, each feeder being controlled by a knife switch.

One center of distribution is located in the basement, ground floor, salon, library, studio, and attic floors, and two centers of distribution at the guests' bedroom floor. For power purposes, one center of distribution is located at the cellar floor only. The method of electric feeding is shown in the diagram of feeders. The conductors for the feeders are all installed in iron conduit, a single conduit being provided for all the conductors in each case. The feeders for the upper floors rise from the house-feeder switchboard to the level of the ground floor, thence they run under the flooring of the ground floor to the rising point opposite the servants' stairs, where they rise to the upper floors, as shown. The conduits for this portion of the feeders are placed against the terra-cotta partition and then furred in by wire lath, which was afterward plastered. The motor circuits provide for six motors, including two for electric elevators, three for electric

dumb-waiters, and one for operating the skylight louvres over the stair well.

Basement (Fig. 78)

The lighting and the wiring of this floor require no special description as it is sufficiently intelligible from the plan. It will be noticed that two junction boxes are shown on the front basement wall. These junction boxes serve for two outside pedestal lights shown on the ground floor plan.

Ground Floor (Fig. 79)

The circuits for the two outside pedestal lights are run in conduits on the basement ceiling as far as the junction boxes on the front entrance wall. The circuits from this point consist of lead-covered conductors set in iron conduits. These lead-covered conductors rise inside of the pedestal fixtures as far as the sockets on the fixture, and special precautions were used to make the outside wiring weather-proof.

The floor outlet in the entrance hall serves for electric lights in an electric fountain located in the center of the hall.

The bracket and chandelier lights in the entrance hall are controlled by four automatic switches, the push-buttons operating the same being located on the wall outside the reception-room, as shown; the bracket lights are controlled in two equal groups and the ceiling lights in two unequal groups. A fifth automatic switch controls the lights located over the main stairs at the level of the library floor.

The bracket lights in the reception-room are controlled in two equal groups by means of push-button switches located near the entrance to the room.

The lights in closets at this floor, as at all the upper floors, are controlled by means of automatic door switches.

In the kitchen, receptacle lights were installed under the hood over the kitchen range; the lights are controlled by a push-button switch near the range.

Night Lights

On the ground floor provision was made for a night circuit, consisting of one light in vestibule, one in entrance hall, and at rear of stair hall. These lights are controlled by a push-button switch located in entrance hall.

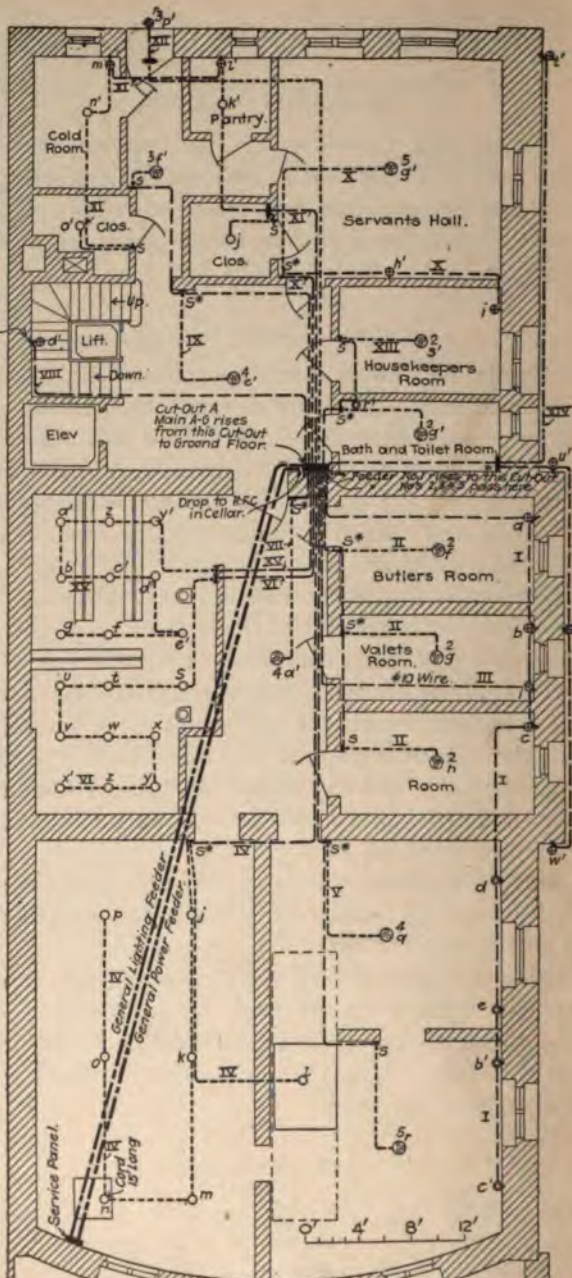

Circuit XIII rises and takes one-Outlet on each Floor above
Cold Room
Clos.
Pantry
Servants Hall.
Clos.
Lift.
Up
Down
Housekeepers Room
Elev
Cut-Out A
Main A-G rises from this Cut-Out to Ground Floor.
Bath and Toilet Room
Drop to R.F.C. in Cellar.
Butlers Room
Valets Room.
#10 Wire
Room
General Lighting Feeder
General Power Feeder
Service Panel.
Cord 15' long
0' 4' 8' 12'

FIG. 78

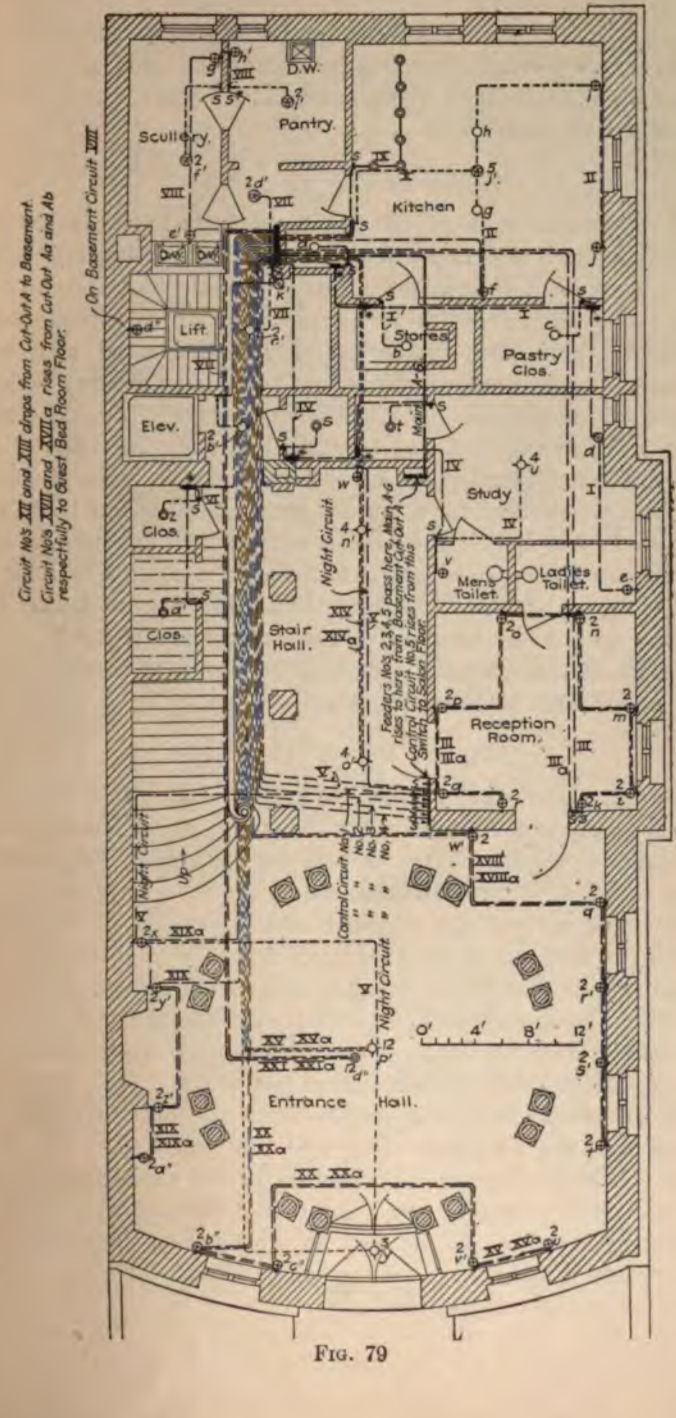

Scullery.
Pantry.
D.W.
Kitchen
Lift.
Stores
Pastry Clos.
Elev.
Study
Clos.
Clos.
Mens Toilet.
Ladies Toilet.
Stair Hall.
Night Circuit
Reception Room.
Entrance Hall.
Up
Control Circuit
0' 4' 8' 12'

Fig. 79

At the library, guest bedroom, and studio floors, provision is made for two one-light brackets located at the ends of the hall. In each case the brackets are controlled by a push-button switch located on the same floor.

Salon Floor (Fig. 80)

The lights at each of the bracket outlets in the salon are supplied by two separate circuits, the circuits being controlled by six push-button switches located near the entrance to the salon. The ceiling outlet is supplied by three circuits controlled by three push-button switches also located near the entrance. By this arrangement, it is possible to get any desired degree of illumination. The bracket outlets and ceiling outlet in the hall are supplied and controlled in a similar manner by push-button switches loacted on the wall near the head of stairs. An outlet is provided for a lantern in front of each of the three windows in the hall. The ceiling outlets and brackets in the dining-room are supplied and controlled in a similar manner to those in the salon and hall, the switches being located near the entrance to the dining-room. Plug outlets are located in the baseboard in the salon, hall, and dining-room, to serve as connections for fans, table lights, etc.

Library Floor (Fig. 81)

Extension outlets are provided in the library at a height of approximately six feet from the floor for providing lights in the future over the bookcases and book-stacks. Plug outlets in the baseboard provide for lights on the reading-tables. The outlets in this room are supplied and controlled in a similar manner to the rooms on the salon floor. The bedrooms are lighted in this manner by bracket lights as is also the boudoir, the outlets being supplied by two separate circuits controlled by push-button switches located near the doors. A plug outlet is provided in all cases on each side of the bed.

At this floor are shown the 48 receptacle outlets which are located between the glass ceiling and the stair well.

At this floor there is a connection in the elevator shaft for the light in the elevator car. The circuit terminates at a cable junction box located in the wall at the back of the shaft. At this point a connection is made with the flexible elevator cable extending to the outlet in the car.

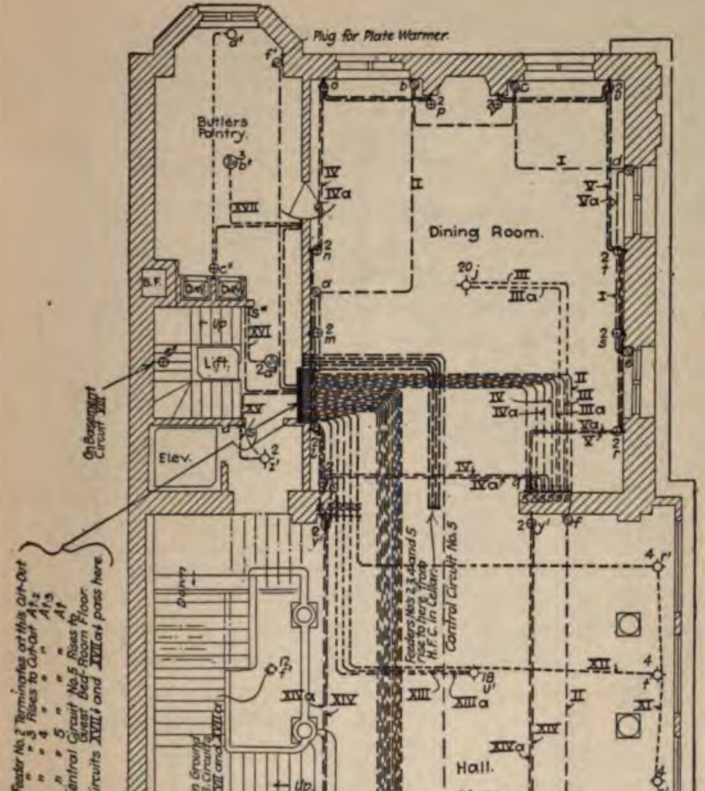

Plug for Plate Warmer.
Butlers Pantry.
Dining Room.
Lift.
Elev.
Hall.
Salon.
Up.
Dn.

FIG. 80

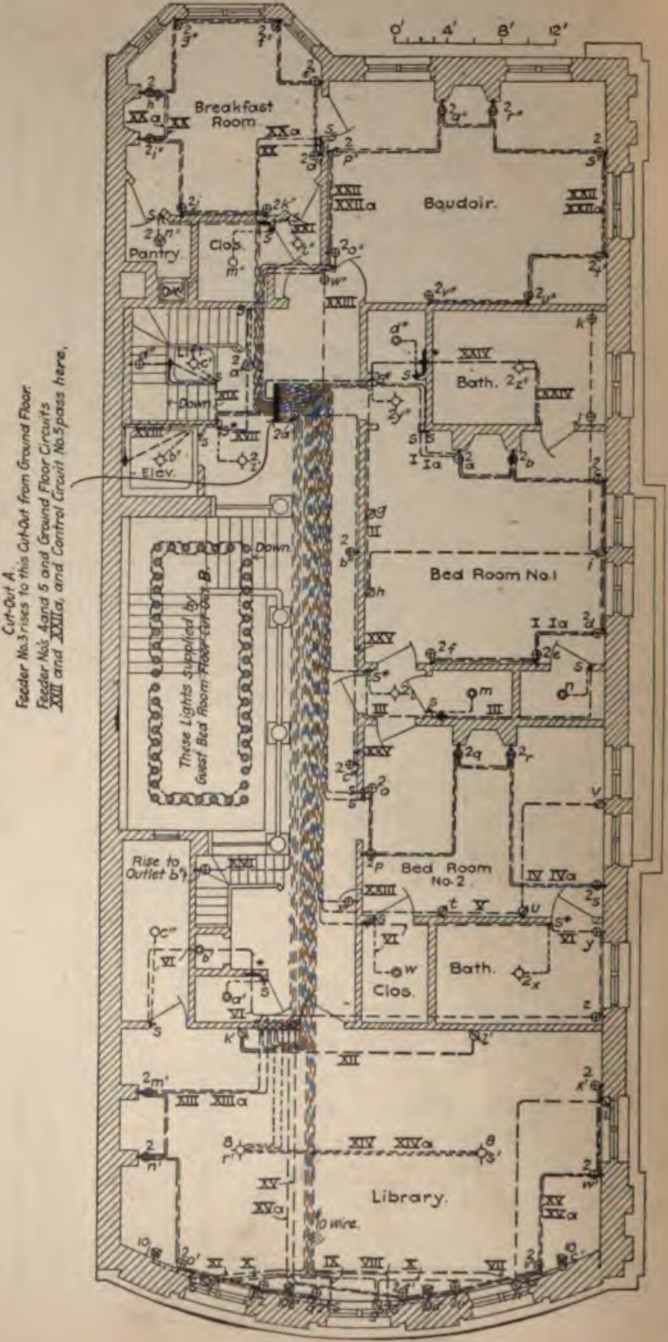

Cut-Out A.
Feeder No.3 rises to this Cut-Out from Ground Floor.
Feeder No's 4 and 5 and Ground Floor Circuits XIII and XXIIa, and Control Circuit No.5 pass here.
Breakfast Room
Boudoir.
Pantry
Clos.
Lift
Down
Elev.
Bath.
Bed Room No.1
These Lights supplied by Guest Bed Room Floor Cut-Out B.
Rise to Outlet b'
Bed Room No.2
Clos.
Bath.
Library.
10 Wire.
0' 4' 8' 12'

FIG. 81

GUESTS' BEDROOM, STUDIO, AND ATTIC FLOORS (Figs. 82, 83, 84)

The lighting and wiring on these floors requires no description, as it is simple, and is clearly shown in the plans.

WIRING OF AN APARTMENT HOUSE

The plan shows a typical floor in an expensive apartment building in New York City. Each floor of this building serves as a single apartment, a separate feeder being provided for each of the apartment floors, the current consumed being measured by an instrument on the switchboard in the basement. The current supply for the building is derived from an isolated plant located in the basement, consisting of two 75-kw. units and one 50-kw. The dynamos are continuous current, compound-wound, 116-volt machines, each being direct-connected to a simple high-speed engine.

The lights in the public halls, stairs, etc., are supplied by vertical circuits rising from the basement, and the current consumed in each of these circuits is measured by a separate meter.

Although the apartments are rented with the light included in the rental, the wiring is so arranged that the current consumed by the occupant of each apartment may be measured and charged for, if desired.

As will be seen from the plan, the cut-out cabinet for each apartment is located near the tradesmen's elevator, just outside the butler's pantry. This arrangement makes it possible for the house electrician to have access to the cut-out cabinet, to test circuits, replace fuses, etc., without entering the apartment itself, and also places the cabinet in an inconspicuous position. The location of lights and switches, the arrangement of circuits, etc., are clearly shown on the plan (Fig. 86) and require no explanation.

WIRING PLAN OF GROUND FLOOR OF A LARGE HOTEL

The plan (Fig. 87) shows the arrangement of lights and the wiring of the ground floor of a large summer hotel located in the White Mountains. On this floor are located the office, dining-room, assembly-room, card-rooms, and the ballroom. The plan is to a great extent self-explanatory and requires little description.

The chandelier outlets in the middle portion of the dining-room are each supplied by a separate branch circuit, controlled by a push-button switch in the cut-out cabinet. The outer

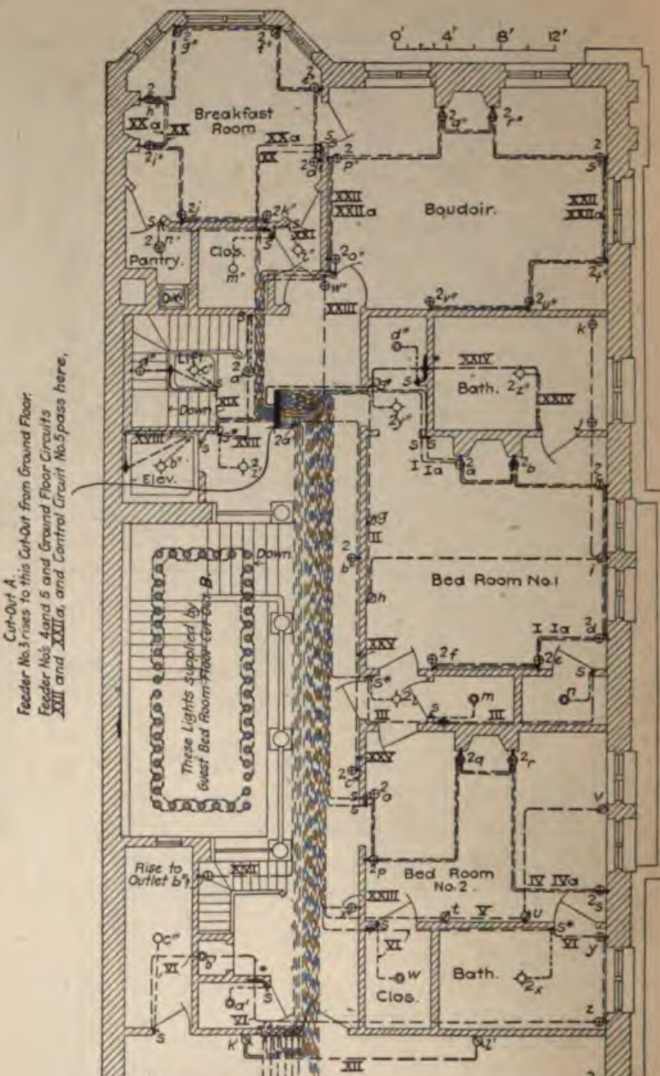

Cut-Out A.
Feeder No.3 rises to this Cut-Out from Ground Floor.
Feeder No's 4 and 5 and Ground Floor Circuits XIII and XXIIa, and Control Circuit No.5 pass here.
0' 4' 8' 12'
Breakfast Room
Boudoir.
Pantry.
Clos.
Lift
Down
Elev.
Bath.
Bed Room No.1
These Lights supplied by Guest Bed Room Floor Cut-Out B.
Down
Rise to Outlet b'
Bed Room No. 2.
Clos.
Bath.
Library.
10 Wire.

FIG. 81

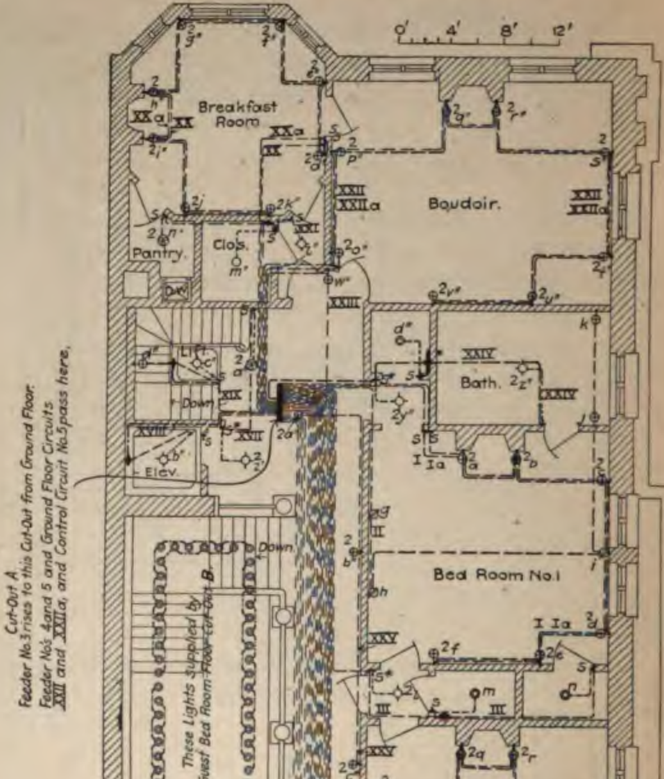

0' 4' 8' 12'
Cut-Out A.
Feeder No.3 rises to this Cut-Out from Ground Floor.
Feeder No's 4 and 5 and Ground Floor Circuits XIII and XXIIa, and Control Circuit No.5 pass here.
Breakfast Room
Boudoir.
Pantry.
Clos.
Lift
Down
Elev.
Bath.
Bed Room No.1
These Lights Supplied by Guest Bed Room Floor Cut-Out B.
Rise to Outlet b"
Bed Room No.2
Clos.
Bath.
Library.
10 Wire.

Fig. 81

Guests' Bedroom, Studio, and Attic Floors (Figs. 82, 83, 84)

The lighting and wiring on these floors requires no description, as it is simple, and is clearly shown in the plans.

WIRING OF AN APARTMENT HOUSE

The plan shows a typical floor in an expensive apartment building in New York City. Each floor of this building serves as a single apartment, a separate feeder being provided for each of the apartment floors, the current consumed being measured by an instrument on the switchboard in the basement. The current supply for the building is derived from an isolated plant located in the basement, consisting of two 75-kw. units and one 50-kw. The dynamos are continuous current, compound-wound, 116-volt machines, each being direct-connected to a simple high-speed engine.

The lights in the public halls, stairs, etc., are supplied by vertical circuits rising from the basement, and the current consumed in each of these circuits is measured by a separate meter.

Although the apartments are rented with the light included in the rental, the wiring is so arranged that the current consumed by the occupant of each apartment may be measured and charged for, if desired.

As will be seen from the plan, the cut-out cabinet for each apartment is located near the tradesmen's elevator, just outside the butler's pantry. This arrangement makes it possible for the house electrician to have access to the cut-out cabinet, to test circuits, replace fuses, etc., without entering the apartment itself, and also places the cabinet in an inconspicuous position. The location of lights and switches, the arrangement of circuits, etc., are clearly shown on the plan (Fig. 86) and require no explanation.

WIRING PLAN OF GROUND FLOOR OF A LARGE HOTEL

The plan (Fig. 87) shows the arrangement of lights and the wiring of the ground floor of a large summer hotel located in the White Mountains. On this floor are located the office, dining-room, assembly-room, card-rooms, and the ballroom. The [illegible] is to a great extent self-explanatory and requires [illegible]

The chandelier outlets in the middle [illegible] room are each supplied by a separate branch circuit [illegible] by a push-button switch in the [illegible]

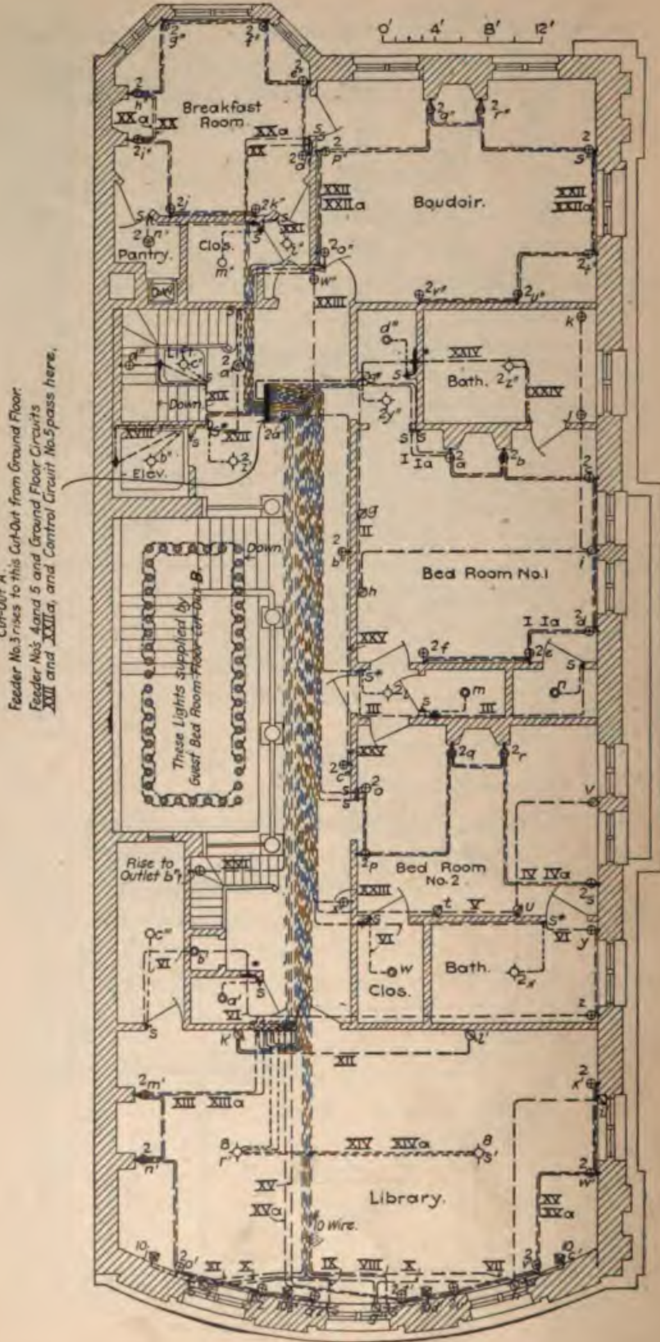

Cut-Out A.
Feeder No.3 rises to this Cut-Out from Ground Floor.
Feeder Nos. 4 and 5 and Ground Floor Circuits XIII and XXIIa, and Control Circuit No.5 pass here.
0' 4' 8' 12'
Breakfast Room.
Boudoir.
Pantry.
Clos.
Lift
Down
Elev.
Bath.
Bed Room No.1
These Lights supplied by Guest Bed Room Floor Cut-Out B.
Down
Rise to Outlet b'
Bed Room No.2
Bath.
Clos.
Library.
10 Wire.

FIG. 81

GUESTS' BEDROOM, STUDIO, AND ATTIC FLOORS (Figs. 82, 83, 84)

The lighting and wiring on these floors requires no description, as it is simple, and is clearly shown in the plans.

WIRING OF AN APARTMENT HOUSE

The plan shows a typical floor in an expensive apartment building in New York City. Each floor of this building serves as a single apartment, a separate feeder being provided for each of the apartment floors, the current consumed being measured by an instrument on the switchboard in the basement. The current supply for the building is derived from an isolated plant located in the basement, consisting of two 75-kw. units and one 50-kw. The dynamos are continuous current, compound-wound, 116-volt machines, each being direct-connected to a simple high-speed engine.

The lights in the public halls, stairs, etc., are supplied by vertical circuits rising from the basement, and the current consumed in each of these circuits is measured by a separate meter.

Although the apartments are rented with the light included in the rental, the wiring is so arranged that the current consumed by the occupant of each apartment may be measured and charged for, if desired.

As will be seen from the plan, the cut-out cabinet for each apartment is located near the tradesmen's elevator, just outside the butler's pantry. This arrangement makes it possible for the house electrician to have access to the cut-out cabinet, to test circuits, replace fuses, etc., without entering the apartment itself, and also places the cabinet in an inconspicuous position. The location of lights and switches, the arrangement of circuits, etc., are clearly shown on the plan (Fig. 86) and require no explanation.

WIRING PLAN OF GROUND FLOOR OF A LARGE HOTEL

The plan (Fig. 87) shows the arrangement of lights and the wiring of the ground floor of a large summer hotel located in the White Mountains. On this floor are located the office, dining-room, assembly-room, card-rooms, and the ballroom. The plan is to a great extent self-explanatory and requires little description.

The chandelier outlets in the middle portion of the dining-room are each supplied by a separate branch circuit, controlled by a push-button switch in the cut-out cabinet. The outer

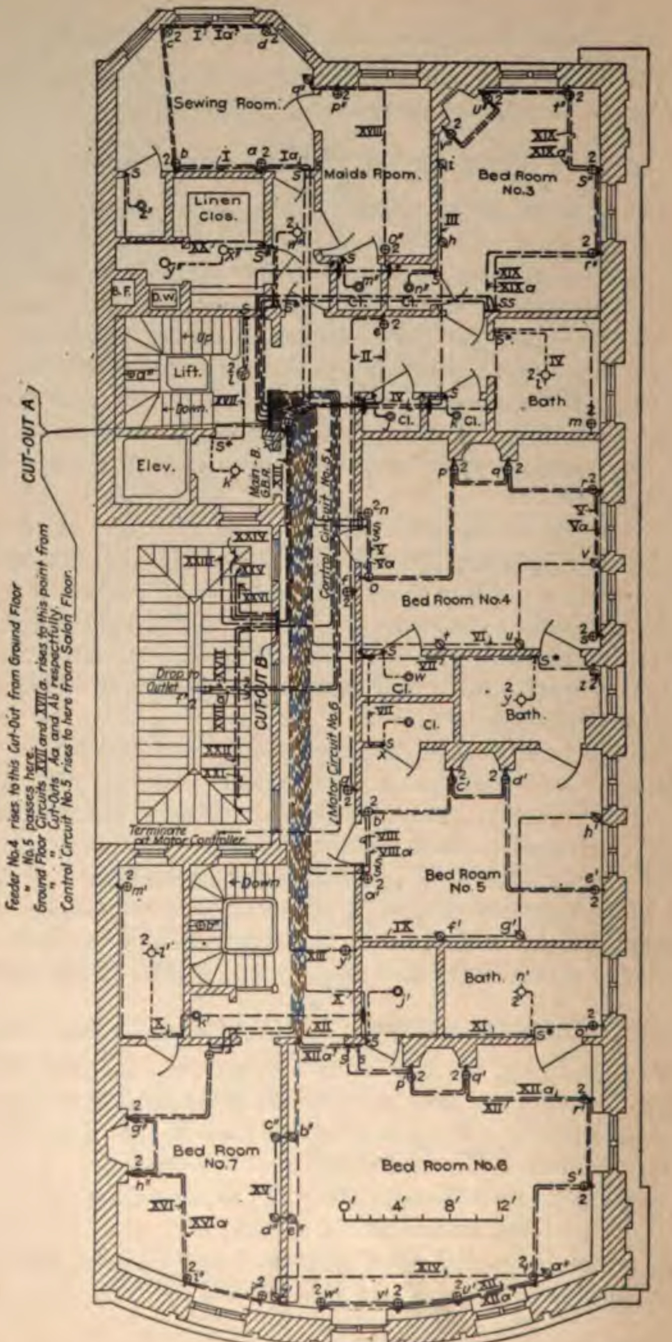

Feeder No.4 rises to this Cut-Out from Ground Floor
" No.5 passes here.
Ground Floor Circuits XVII and XVII a. rises to this point from
" " Cut-Outs Aa and Ab respectfully.
Control Circuit No.5 rises to here from Salon Floor.
CUT-OUT A
CUT-OUT B
Sewing Room
Maids Room
Bed Room No.3
Linen Clos.
B.F.
D.W.
Lift.
Elev.
Bath
Bed Room No.4
Bath.
Bed Room No.5
Bath.
Bed Room No.7
Bed Room No.6
Control Circuit No.5
Motor Circuit No.6
Drop to Outlet
Terminate at Motor Controller
0' 4' 8' 12'

Fig. 82

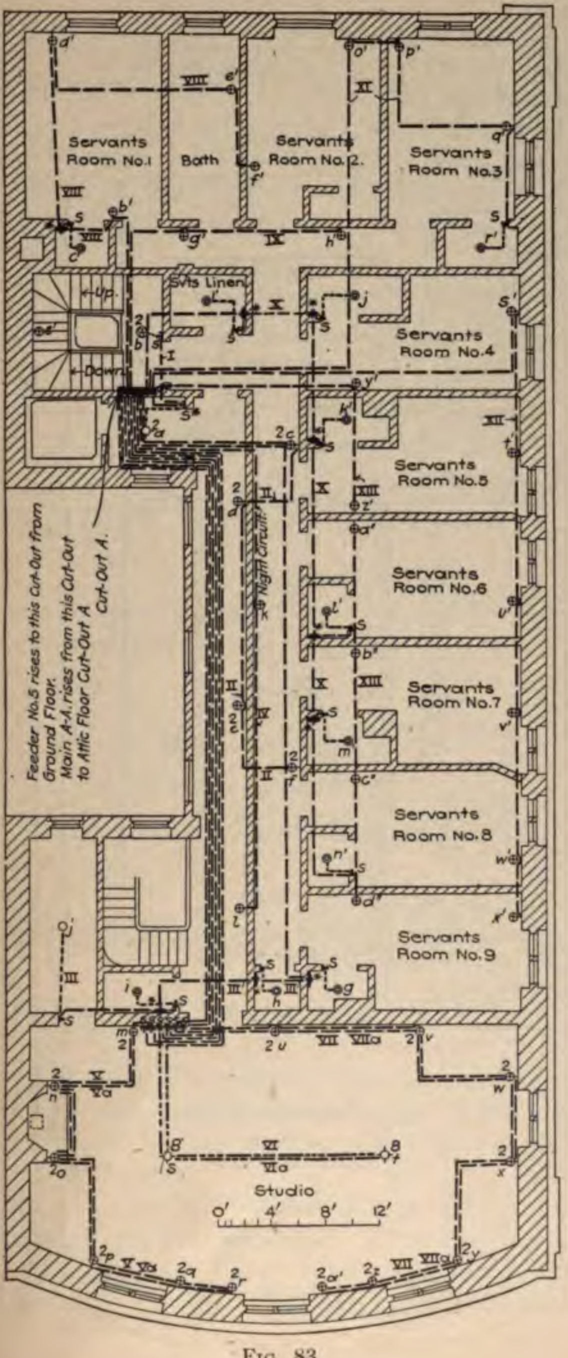
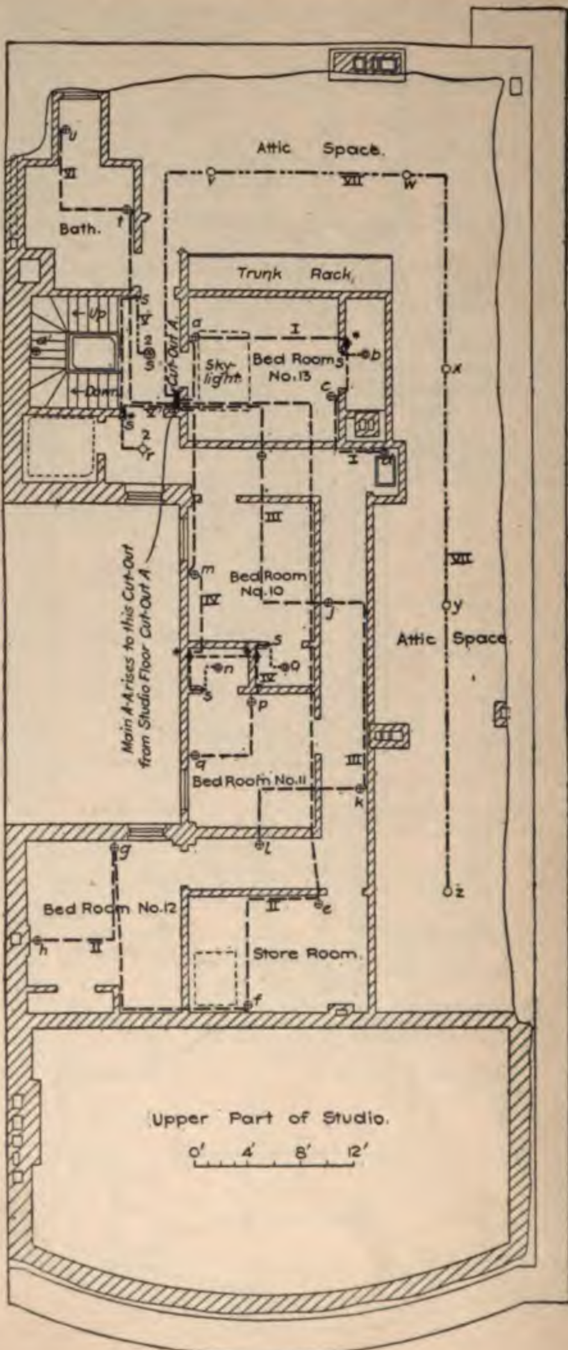

Servants
Room No.1
Bath
Servants
Room No.2.
Servants
Room No.3
Svts Linen
Servants
Room No.4
Servants
Room No.5
Servants
Room No.6
Servants
Room No.7
Servants
Room No.8
Servants
Room No.9
Studio
Up
Down
Night Circuit
Feeder No.5 rises to this Cut-Out from
Ground Floor.
Main A-A rises from this Cut-Out
to Attic Floor Cut-Out A.
Cut-Out A.
0' 4' 8' 12'

FIG. 83



Attic Space.
Bath.
Trunk Rack.
Sky-light
Bed Room No. 13
Cut-Out A
Bed Room No. 10
Main A-A rises to this Cut-Out from Studio Floor Cut-Out A
Attic Space
Bed Room No. 11
Bed Room No. 12
Store Room.
Upper Part of Studio.
0' 4' 8' 12'

Fig. 84

group of chandelier outlets in the dining-room is supplied by two separate branch circuits, each of which is controlled by a separate switch at the cut-out cabinet. In addition to this, and for convenience, all of the ceiling lights in the inner group are controlled by a single knife switch at the cut-out cabinet, and all of the lights in the outer group are similarly controlled. By this arrangement it is possible to get any degree of refinement desired in the lighting.

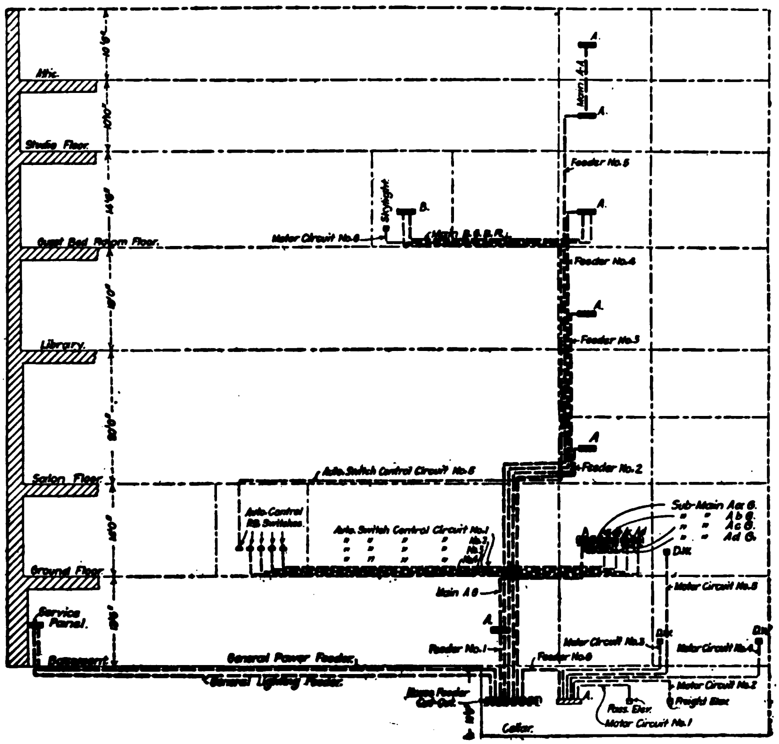


FIG. 85

The ceiling lights in the assembly hall are controlled in two large groups by knife switches located in the cut-out cabinets, the outlets being wired in alternation. The bracket outlets are controlled in a third group.

The ballroom is principally lighted by means of 300 reflector ground-glass lamps placed in the ceiling. These lamps are wired in alternation and controlled in two groups at the cut-out cabinet. Wiring was provided in the ballroom for four additional chandelier

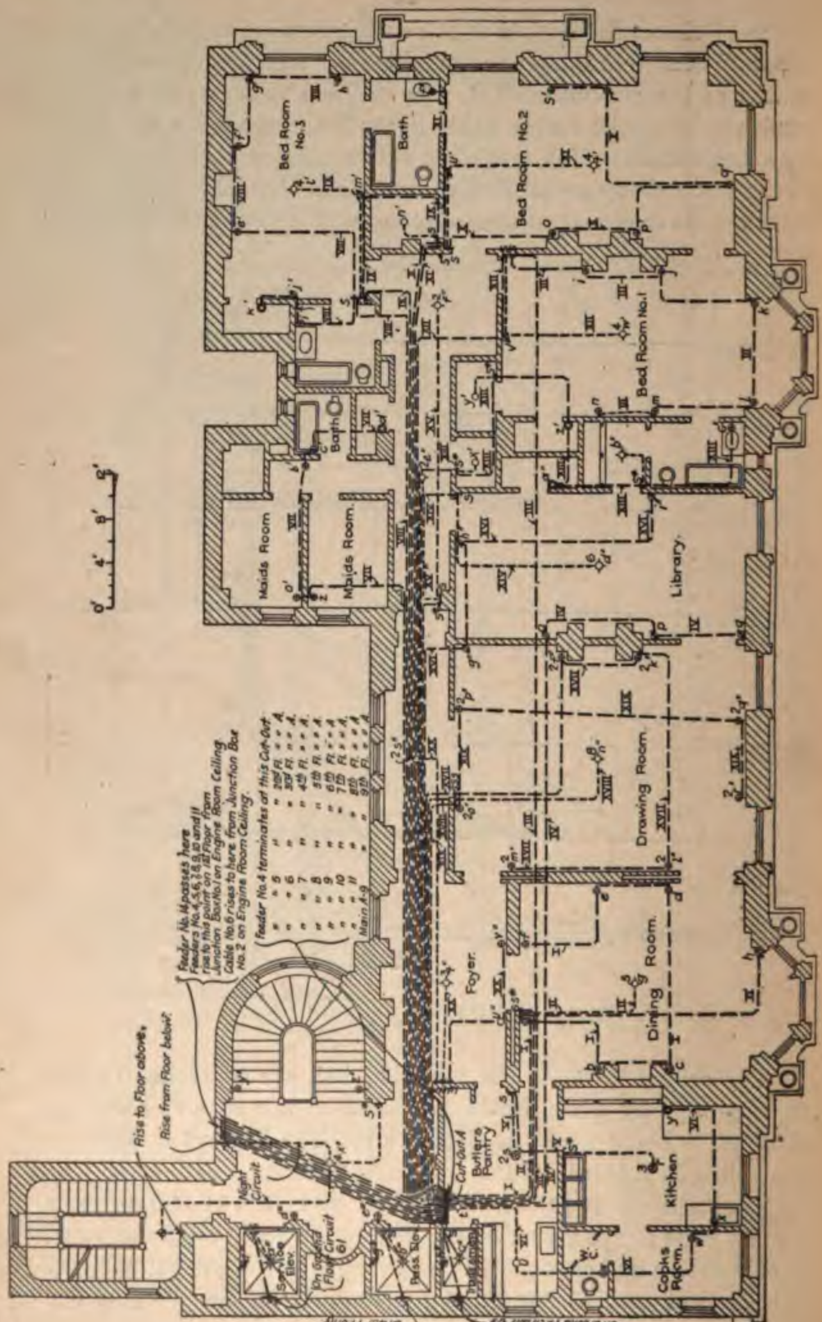
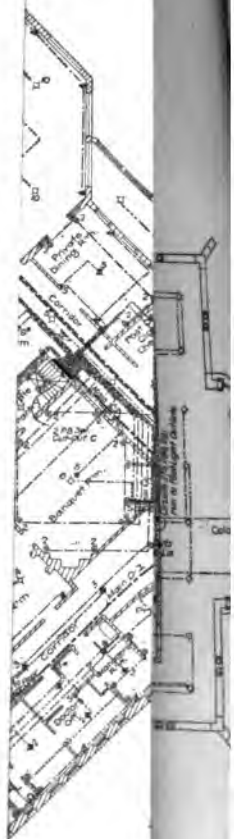

Bed Room No.3
Bath
Bed Room No.2
Bed Room No.1
Maids Room
Maids Room
Bath
Library
Drawing Room
Dining Room
Foyer
Butlers Pantry
Kitchen
Cooks Room
Rise to Floor above.
Rise from Floor below.

FIG. 86



outlets of 16 lights each, but the fixtures were never installed, as it was not found necessary or desirable. Bracket chandelier outlets were also provided for lighting the alcoves at the sides of the ballroom. As it was intended to use the ballroom at times for entertainments and theatrical purposes, provision was made for footlights on the stage and for ceiling lights over the stage.

WIRING PLAN OF FIRST FLOOR OF A CLUB BUILDING

The plan (Fig. 88) shows the wiring of a characteristic floor in a club building located in East Sixtieth Street. On this floor are located the lounging-room, magazine and newspaper rooms, two card-rooms, service-room, etc.

Owing to the arrangement of this floor it was found impracticable to have more than one center of distribution for the lighting circuits, and this center of distribution is located in a rear hall.

Floor outlets were installed in the magazine and newspaper rooms for providing means for supplying current to fixtures to be located on the tables. Pedestal lights are located near columns in the lounging-rooms, for standard fixtures. Plug outlets are located at various points along the walls for supplying current to movable fixtures to be located on tables, for portable fans, etc. The ceiling lights in all cases are controlled by push-button switches, which are in most cases located in the cut-out cabinet.

SPECIFICATION

For Electric Wiring for a Private Residence in New Jersey
Dated, New York, June, 1905.

Charles E. Knox,
Electrical Engineer,
76 William Street, New York City.

All proposals must be addressed to the Electrical Engineer.

General Conditions

(*a*) Plans:

This Specification includes five (5) plans, as follows: —

Wiring Plan of Basement.
Wiring Plan of First Floor.
Wiring Plan of Second Floor.
Wiring Plan of Attic.
Diagram Sheet.

(*b*) Explanations:

Any information or explanation required concerning the meaning and force of any portion of these Specifications or plans will be

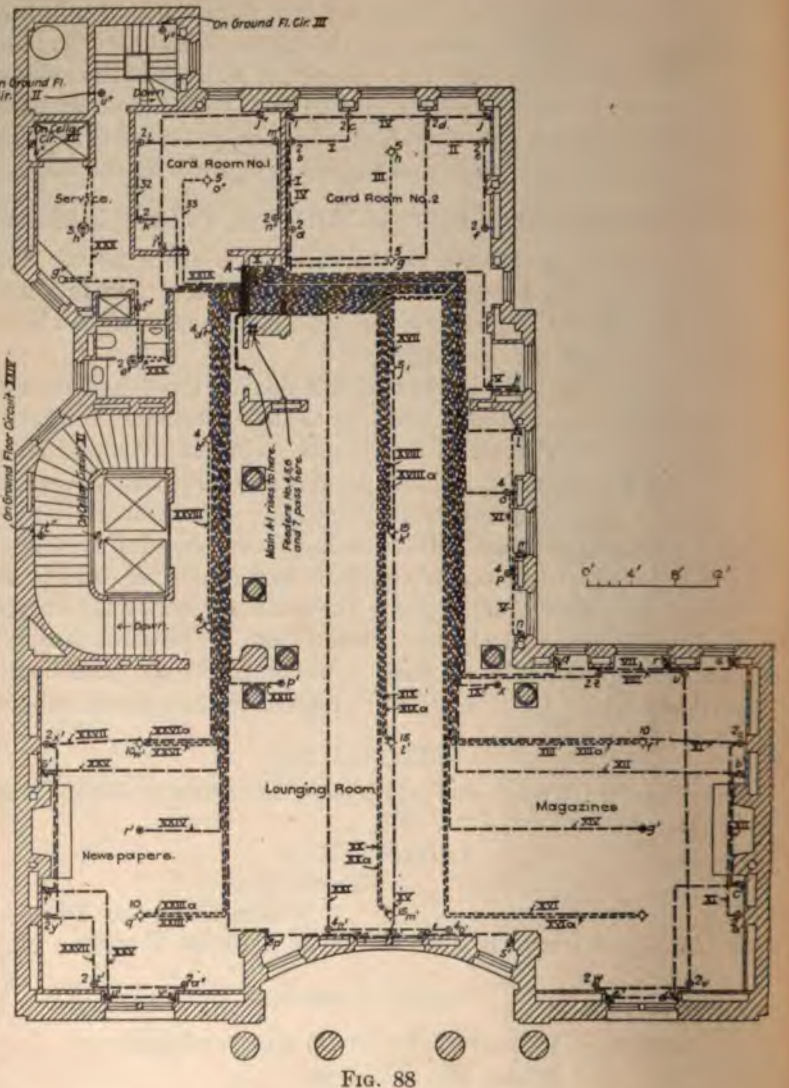


FIG. 88

furnished by the Electrical Engineer whose ruling and decision will be final and conclusive on any points or questions brought up. Any explanations requisite in connection with the preparation of estimates must also be obtained from the Electrical Engineer.

(c) SCOPE OF CONTRACT:

It is the intent of this Specification to include all materials or

labor necessary to install and put into good working condition the equipment specified in this Specification, or indicated on the plans.

Any materials or labor not specifically mentioned or excluded, that may be found necessary to complete any portion of the equipment in substantial manner, shall be furnished by the Contractor, just as if specifically mentioned in this Specification, and without extra cost to the Purchaser.

(*d*) CHANGES:

No changes will be permitted in this Specification, or in the plans accompanying the same, except in minor details or for good legitimate cause, or except when made necessary by reason of altered conditions or changes in the building.

No such changes shall be made without the authority of the Electrical Engineer.

The Purchaser shall have the privilege of ordering any changes that may be deemed desirable or necessary, for the hereinabove specified reasons or for other legitimate reasons, at any time before the completion of the work.

All such changes, involving no additional cost to the Contractor and no loss or expense to the Purchaser, are to be made free of expense to the Purchaser.

For all changes ordered by the Purchaser, or his representative, the settlement shall be made when possible by reference to the "stated prices" which are required to be quoted in the Contractor's proposal, as specified hereinafter.

For any addition to, or omission from, the circuit work, or for any other change required in the installation, involving additional cost to the Contractor, and for which no adequate basis of settlement has been provided in the "stated prices" aforesaid, the Contractor must first give written notice of such additional cost, and must submit an estimate; and a special order shall be issued for the said addition, omission, or change, before the work of making said change is begun.

Bills of all extra work must be rendered promptly on the completion of said extra work, accompanied with all items, and details necessary for the proper audit of said bills.

The Purchaser shall receive credit for the value of all materials or work discarded and not installed.

No allowance shall be made for extra work unless these conditions are fully complied with.

(*e*) INSPECTION:

The details of the installation will, in general, be under the direction and subject to the approval of the Electrical Engineer; and the Purchaser reserves the right to reject any portion of the equipment or installation work found by the Electrical Engineer

to be below the commercial standard required by this Specification.

(*f*) Repairs, Defects, etc.:

The Contractor must use only the best apparatus, appliances, and materials, and must employ labor skilled and competent for the work. He is to be responsible for and must repair or make good, without expense to Purchaser, any and all defects or derangements occurring or arising in the specified equipment within a period of six months after its acceptance; provided the said defects be due to imperfect apparatus, appliances, or materials, or imperfect workmanship or installation work furnished by the Contractor, and are not due to careless or improper operation of the equipment by the Purchaser's representative.

(*g*) Other Trades:

In case any portion of the work to be done under this Specification involves mason-work, iron-work, carpenter-work, plumbing, steam-fitting, or any work pertaining to other trades employed in doing like work in the building, the Contractor must have the said work done in such manner as to obviate all antagonism on the part of, or difficulty with, the particular trade engaged in doing such work.

The Contractor should arrange, whenever possible and practicable, to have any of the hereinabove mentioned work pertaining to other trades done by the General Contractor, or Sub-Contractor, doing the rest of such work in the building.

The Contractor for the work covered by this Specification will be required to co-operate with the other Contractors, to avoid delay and obviate defects in any part of the equipment, and to prevent damage or loss of materials.

(*h*) Accident:

The Contractor is to be responsible for his own acts, and those of his employees, Sub-Contractors, etc., and is to bear any loss resulting from his or their neglect, or the violation of any Ordinances; or any accident caused by him or them or by the machinery until the equipment shall have been accepted.

(*i*) Insurance:

All materials and work are to conform in all respects to the requirements and regulations of the fire insurance and inspection authorities having jurisdiction, including the latest amendments and modifications in their rules. Certificate of inspection must be furnished by the Contractor, from each and every inspection bureau.

SUMMARY SHEET

The summaries of the principal items comprised and included in the Electric Wiring and Circuit Work, specified in Section I of this Specification, are as follows:

13 outlets for 14 Incandescent light chandelier fixtures.
41 outlets for 41 Incandescent light bracket fixtures.
8 outlets for 8 Incandescent light ceiling receptacles.
2 outlets for 2 Incandescent light wall sockets.
10 outlets for 10 Incandescent light drop cords.
7 outlets for 7 Insertion plug connections.

Total number of outlets — 71
Total number of lights — 81

1 Feeder.
1 Cut-out and Cabinet.
1 Service Panel, Switch and Cabinet.
16 Branch Circuits.
20 Local D. P. Push-Button Switches.
11 Local 3-Point Push-Button Switches.
2 Local 4-Point Push-Button Switches.
2 Local Rotary Snap Switches.
106 Outlet Boxes (of all kinds).
10 Drop-Cord Outfits — 10 lamp shades and holders for same.
Average length of cord (flexible) 3 feet.

(Note. 7 of the drop-cord outfits are to have keyless sockets; 3 of the drop-cord outfits are to have pull sockets.)

8 ceiling receptacles — 8 metal rosettes for same.
2 key wall Sockets.

SECTION I. ELECTRIC LIGHT WIRING

1. Electric Current Supply:

The electric current supply for the building will be derived from the street mains of the local electric lighting company.

The service for lighting will be alternating current, 110 volts, secondary pressure. The service wires will enter the building in the attic.

The three-wire system will be used for feeder and mains, and the two-wire system for branch circuits.

2. Leakage and Insulation:

The insulation of the circuit work from the feeding point to the outlet shall be made sufficiently perfect, in any circuit or branch under full current pressure and load, to prevent a leakage exceeding one 200,000th part of the current in said circuit or branch.

3. Lamps:

No lamps will be included in the present contract.

4. Definite Locations:

The locations indicated on the Wiring Plans are supposed to be approximately correct, but are understood to be subject to such revisions as may be found necessary or desirable at the time that

the circuit-work is installed, in consequence of increase or reduction of the number of outlets, or in order to meet difficulties, or to simplify the work, or for other legitimate cause.

The precise and definite location of all conduits, conductors, circuit-appliances or accessories, is to be, in every instance, as directed or approved by the Architect or Electrical Engineer.

No allowance will be made the Contractor for any and all changes necessitated in the circuit-work in consequence of the Contractor's neglect to have the said locations defined or approved by the proper person or persons.

5. Feeders and Mains:

The Feeder Sheet shows the method of feeding, and gives all the necessary data relating to the feeders and mains.

(N.B. This Sheet is not intended to indicate the exact location, heights, etc., of cut-outs, switches, etc., or the exact course of the feeders and mains.)

6. Schedule of Sizes:

The sizes of wires or cables to be used for each of the feeder or main conductors are given in the tables of data on the Feeder Sheet.

The lengths taken as basis of calculation are estimated from the plans, by scale measurements, with allowance for bends, terminals, etc.

The Contractor must verify all lengths by actual measurement made at the building at the earliest possible date; and all discrepancies must be reported to the Electrical Engineer.

The Contractor shall provide and install conductors of the exact and precise length requisite for each case.

7. Branch Circuits:

The Wiring Plans show the principal features and details of the circuit wiring for the various branch circuits.

See Clause 4.

All the branch circuits shall be of No. 14 B. & S. gage, unless otherwise indicated on the plans.

8. Tube Conduits:

The Contractor shall provide a single conduit for each set of conductors for feeders, mains, and branch circuits.

All the conduits shall be of the enameled (unlined) type. The conduits shall be of the Loricated, Electroduct, or other equally good make, approved by the Electrical Engineer.

For the branch circuits, the Contractor shall use one half inch conduits. For the feeder and main conductors, the minimum sizes allowed are scheduled on the Feeder Sheet.

9. Arrangement of Conduits:

The wiring conduits are to be set exposed only at certain places (such as where the walls and ceilings are not to be finished), when

such exposed conduit work is, for good reason, permissible or preferable.

At all other places, the conduits shall be set so as to be concealed under or between floors, in walls, partitions, chaces, behind lathing, furring, etc.

The tubes shall be properly secured in position by means of approved support and fastening. Where the proper support and fastening cannot otherwise be secured, the Contractor shall provide and set suitable wooden supports to which the conduits shall be secured, in approved manner.

The arrangement of conduits shall be, in general, subject to the direction and approval of the Electrical Engineer in every detail.

10. Protection of Conduits:

All conduit tubes run exposed shall be painted with a protective coat of paint or compound adequate to protect them against corrosion, rust, etc.

11. Conduit Bends:

The Contractor will be permitted to make bends in the one half inch conduits instead of using made elbows and offsets, provided the bends be properly made, and in a manner approved by the Electrical Engineer.

For all the sizes of conduits larger than one half inch, the Contractor will use the special elbows and offsets made for the purpose.

12. Conduit Ends:

Use particular care in running the conduits to the various outlets, cut-out cabinets, etc., and in connecting them with the outlet boxes, connection compartments of cut-out cabinets, etc. Make the length of conduit such that the ends will fit precisely and properly at such points. Make all such runs of the conduits neatly, symmetrically, and avoid bunching or crowding the conduit ends unduly.

Provide and use an approved conduit-end insulator (or an approved equivalent) for each and every conduit-end at cut-out cabinets and at all outlets as required by the Insurance Rules.

Plug each section of conduit at both ends with cork as soon as installed, to prevent its filling with plaster, dust, etc., and to obviate moisture condensation therein.

13. Outlets:

Provide and set a special iron outlet box for every electric light outlet and for every local switch outlet. Said outlet-box to be of approved design and construction, of form and dimensions suited and adapted in every instance to its specific location, the kind of fixture to be used, the number and arrangement of conduits, gas-pipes, etc., connecting therewith.

Special designs and makes of outlet boxes will be required, and

shall be provided by the Contractor for all cases where the space, and other conditions, limitations, peculiarities, or requirements, influencing the arrangement, features, and details of the outlet shall necessitate said special outlet boxes, for the proper, complete, workmanlike outfit and equipment of the particular outlet or outlets.

The particular kind and make of outlet box used must be submitted to and approved by the Electrical Engineer.

The Bossert outlet box will be approved.

14. Fixture Supports:

Provide and install at each lighting fixture outlet an approved fixture support.

At "combination" outlets the gas-pipe may be utilized for the fixture support.

At "electric" outlets, a special supporting device will be required, as follows:

(*a*) For ceiling or chandelier fixtures the support may consist of iron pipe of approved diameter, suitably fastened and secured to the framework of the ceiling, or to the floor beams, arches, etc., of the floor above, by a tee or angle affixed to said pipe.

(*b*) For "bracket" or "side" fixtures, the support shall consist of a special flanged metal stem attached to the outlet box and having a threaded end of proper length and otherwise suited for the fixture insulating joint.

The flanged portion shall have a broad base and it shall be securely attached to the outlet-box at not less than three points.

15. Cut-out Cabinets:

All cut-out cabinets (including doors and trims) required in connection with this contract will be provided by the Contractor.

Each cut-out cabinet shall consist of a box of proper form and dimensions, with a connection compartment of not less than three inches on all four sides of the cut-out panel. The front portion of the cabinet shall consist of a door (provided with approved lock and key) with suitable approved wooden trim; the door and trim shall match the surrounding woodwork.

The connection compartment of the cabinet shall be lined with sheet iron of approved thickness. The door shall be lined on the inside with slate, not less than five sixteenths ($\frac{5}{16}$) of an inch thick.

The design of each cut-out cabinet must have the approval of the Electrical Engineer.

16. Cut-outs:

All cut-outs shall be of the "panel" type, with metal bus-bars, connecting bars, etc., mounted on a slate slab.

Each panel shall be encased, when in proper position in the cut-out cabinet, by slabs of slate not less than five eighths ($\frac{5}{8}$) of an inch thick, of width equal to the full depth of the cabinet, and

securely fastened to the bottom of the cut-out cabinet by special angle iron supports, or in other approved substantial manner.

Holes shall be drilled in the said slabs, one for each individual conductor, of suitable size therefor, and located opposite the particular cut-out connector to which it corresponds.

Each cut-out panel shall be made of approved slate, not less than seven-eighths ($\frac{7}{8}$) of an inch thick, of proper, adequate form and dimensions for its purpose, with face finished in approved manner, and having mounted thereon the bus-bars, connecting bars, and all other cut-out appliances.

The design, construction, and proportions of all current-carrying parts and contacts shall be based on the same allowances for current, density, etc., as specified in Clause 19 (Switches).

All exposed metal parts shall be finished bright, polished, and lacquered.

All circuit cut-out connections shall be double poled.

The Contractor must submit detailed drawings to the Electrical Engineer of all cut-out panels within ten (10) days of the award of the wiring contract; said drawings must be approved before the outside (rough) boxes for the panels are made.

All fuse connections shall be made by means of suitable approved enclosed fuses. Each branch circuit shall be controlled by an approved knife switch. The clips and blades of the knife switch must be of sufficient size to prevent the possibility of their getting out of alignment or becoming loose or bent by the operation of the switches.

Each cut-out panel is to be provided with suitable approved means of detecting and locating blown fuses, open circuits, etc. This may consist of a lamp outfit including a receptacle with suitable approved plug contacts attached to the base. The plug contacts to be so arranged as to make it possible to utilize the outfit for testing each of the branch circuit connections, mains and feeder connections.

17. Schedules:

Provide suitable means of indicating at each cut-out connection the circuit corresponding thereto, by stamping the circuit number or name letter upon the cut-out bus-bars.

Provide and place in each cut-out box, on the inside of the door, under a glass plate secured to said door, by means of an approved metal frame, a suitable schedule made out on an approved blank, giving the name of the Feeder or Main supplying the group or groups of cut-outs in said cut-out cabinet and of every Main or Branch Circuit originating at said cut-out or cut-outs; also the section or portion of the building supplied thereby; also the proper size or capacity of fuse required therefor.

18. FUSES:

Provide all the necessary fuses, and make all the necessary connections between circuits at cut-outs.

Provide and furnish an entire duplicate set of fuses for each and every cut-out connection. This duplicate set shall be in addition to the fuses used up to the time of the acceptance of the contract.

All fuses shall be of the enclosed Cartridge type of the D. W. No-Arc, or other equally good approved kind of make.

19. SWITCHES:

The type and make of switches used, and the details of their installation, shall be subject to the approval of the Electrical Engineer.

Samples shall be submitted for approval.

(*a*) *Knife Switches:* All knife switches shall be made of pure rolled copper only.

The design, proportions, workmanship, and finish shall be, in general, the same as for high-class switchboard work, and shall be as approved for each type and size of knife switch.

(*b*) *Flush Switches:* These switches shall be of the double-pole push-button type, with "flush" face plate of approved make, material, and finish.

(*c*) *Snap Switches:* These switches shall be of the rotating "snap" type, of approved make, and shall be used as substitute for Push-Button Switches only where the said push-button switches are not suitable or desirable, and only with the permission of the Electrical Engineer for each case.

The Diamond H. switch made by the Hart Manufacturing Company is approved. Other switches may be submitted by the Contractor for approval.

(*d*) N.B. Every "Push-Button" Switch and every "Snap" Switch shall be so made that it will readily and unmistakably indicate whether it is "on" or "off."

(*e*) *Locations:* The Contractor is specially notified that the locations given or indicated in the Specification, or on the Plans, for the local switches, are subject to modification. In the case of local switches to be set at or near the doors, the definite location will depend upon and may be influenced by changes in the location, arrangement, or the "swings" of the door. The Contractor shall duly ascertain and note any and all such changes.

No local switch is to be installed until the definite location of the same has been duly determined or approved by the Purchaser or his representative.

20. WIRES:

All wires shall be of refined copper of not less than 98 per cent conductivity, properly tinned, and provided with insulation and

covering of the most perfect and durable kinds in the market. The insulation shall be of quality such as used for Grimshaw, Habirshaw, or Bishop wires of the highest grade, or other equally good grade or brand, approved and accepted by the Electrical Engineer, in writing.

For double conductors intended to be used in the same conduit (for branch circuits, etc.) use two distinct wires, each provided with its own insulation, of the proper quality and thickness, and with a protective covering of approved braid; or else use duplex conductors, made up of a pair of such wires bound together with an approved braid.

For all conductors of sectional area greater than No. 8 B. & S. gage use approved stranded conductors.

Flexible cords shall be made up of finely stranded wires of total sectional area equal to No. 15 B. &. S gage.

No wires to be used unless sample has been submitted and has been approved in writing.

In the case of wires of Nos. 14 to 12 B. & S. gage the insulating resistance shall be not less than 500 megohms per mile, after immersion of 5 days in water, at temperature of 25 to 35 degrees Centigrade, and after electrification of five minutes using an e.m.f. of 500 volts. The insulation for all wires of other sizes shall be in due proportion to this amount, as required for the resistivity and thickness of insulation.

For flexible cords the insulation resistance shall be not less than 50 megohms per mile, under the same test conditions aforesaid.

21. Samples of Wire:

Immediately after the contract is awarded, the Contractor must furnish the Electrical Engineer with samples of wires of the size and length desired, for making suitable and proper tests of the same.

22. Joints:

All wires shall be continuous between the points they connect, such as from outlet to outlet, from cut-out to cut-out, switch, junction box, etc. No joints shall be made except by special permission of, and in manner prescribed by, the Electrical Engineer.

23. Sockets:

All sockets shall be of the Weber or other equally good approved manufacture.

For each "drop cord" outlet, listed in the schedule, provide and install the fixture "rosette," the flexible cord, a ball cord adjuster, and a drop-cord (keyed) socket; also provide the lamp shades and holders listed on the Summary Sheet.

For each wall socket listed in the schedule provide and install a porcelain base socket receptacle, having a key socket.

For each "receptacle" outlet listed in the schedule provide and install a porcelain socket receptacle having keyless socket.

Each outlet outfit shall be installed in substantial and workmanlike manner. The design and make of each outfit, and the manner of installing the same, must have the approval of the Electrical Engineer.

24. Insertion Plugs:

Provide, set, and connect insertion plug receptacles requisite for the insertion plug outlets indicated on the plans and scheduled in the Schedule of Outlets and Lights.

The outfit will include the receptacle part of the insertion plug only, and no plugs or flexible cord are to be provided.

Insertion plug receptacles of the Diamond H. manufacture will be approved

25. Cutting, Chacing, etc.:

All cutting, chacing, drilling, etc., in connection with the work covered by this Specification, will be done under other contracts.

26. Fixture Connections:

The present contract will not include the setting of fixtures, but it will include the connecting of all branch circuits to the fixture wiring.

No fixture cut-outs will be used.

The Contractor shall test the fixture wiring, and shall make sure that it is free from leaks, grounds, or crosses, both before and after being connected to the branch circuits.

All fixture wiring found defective in any respect shall be reported to (and is to be repaired by) the Fixture Contractor.

GENERAL DESCRIPTION OF CIRCUIT WORK

27. Building:

The Building consists of Basement, two stories, and Attic.

The heights of the stories are indicated on the Diagram Sheet.

The building is of frame construction throughout.

28. Electric Current Supply:

The supply of electric current will enter the building (overhead) and the service supply switch and meter will be placed at or near the point shown on the Attic Plan as directed later.

At some future time the service lines may be run underground, and the present contract is to include an inch and a quarter conduit, from Cut-Out A, at first floor to the basement ceiling, through which the service main may run later from the basement to Cut-Out A, without disturbing the Cut-Out Cabinet or partition. The length of this conduit will not exceed ten feet.

The meter will be provided by the electric lighting company. The present Contractor will be required to furnish a service switch,

and shall mount the same on a slate panel. The slate panel is to be sufficiently large to mount the meter thereon. The Contractor shall also provide an approved plain wooden cabinet, properly lined, in which the service switch and meter panel shall be placed. The meter will be installed and connected by the electric lighting company. The service switch shall be triple-poled and of 50 amperes capacity.

29. MULTIPLE POINT SWITCH CIRCUITS:

As indicated on the plans, there will be five multiple point switch circuits, or branches of circuits, arranged so that various lights may be controlled from two or more points. The connections of the outlets and switches are clearly indicated on the Diagram Sheet.

30. SWITCH CONNECTIONS:

All switches must be connected with the white (lights "on") push-button uppermost.

In all cases where switches are placed next to push-buttons, the switch shall be placed nearest the door.

31. FIRST FLOOR:

The two plug outlets and the snap switches controlling them may be placed either on the side of the mantle, or else on the shelf of a book-case to be placed next the mantle, on each side. The exact arrangement and location of these two plug outfits shall be as directed at the time of installation.

Outlet "*o*" in the Living Room will be "capped up" and may serve for a fixture to be installed later. The Contractor shall not install any conductors between the switch and this outlet. The switch shall be connected to control the two bracket outlets — *p* and *q*.

The plug outlet "*r*" in Living Room, shall be placed in the base board directly under the switch.

The Contractor shall provide an approved pull socket for each of the drop-cord outlets — *d'*, *e'*, and *f'* — located in Rear Hall, Servants' Dining Room and Passage, respectively. These sockets shall be of the General Electric or other equally good approved make. Samples must be submitted to the Electrical Engineer.

32. SECOND FLOOR:

The plugs in the Bedrooms are to be placed on the wall at a distance between five and six feet from the floor; the exact height shall be as directed later.

CHAPTER XIII

OVERHEAD LINE WORK

It is not the intention to consider in this chapter overhead line work for long transmission lines, but simply to consider briefly the requirements for overhead line work, such as might be encountered in isolated or industrial plant work.

The conductors for overhead line work should have double-braided weather-proof insulation, described elsewhere in this book. Where conductors are run exposed on the walls or roofs outside the buildings, similar forms of construction may be used to those described for interior work.

The rules covering outside wiring are given under Clause B (outside work) of the National Electric Code, and the portions relating to work discussed in this book are as follows (corrected up to January 1, 1906):

Outside Work

(*Light, Power and Heat. For Signaling Systems, see Class E.*)

ALL SYSTEMS AND VOLTAGES

12. Wires

a. Service wires must have an *approved* rubber insulating covering. (See No. 41.) Line wires, other than services, must have an *approved* weather-proof or rubber insulating covering. (See Nos. 41 and 44.) All tie wires must have an insulation equal to that of the conductors they confine.

In risks having private generating plants, the yard wires running from building to building are not generally considered as service wires, so that rubber insulation would not be required.

b. Must be so placed that moisture cannot form a cross connection between them, not less than a foot apart, and not in contact with any substance other than their insulating supports. Wooden blocks to which insulators are attached must be covered over their entire surface with at least two coats of water-proof paint.

c. Must be at least seven feet above the highest point of flat roofs, and at least one foot above the ridge of pitched roofs over which they pass or to which they are attached.

Roof structures are frequently found which are too low or much too light for the work, or which have been carelessly put up. A structure which is to hold the wires a proper distance above the roof in all kinds of weather must not only be of sufficient height, but must be substantially constructed of strong material.

b. Must be protected by dead insulated guard irons or wires from possibility of contact with other conducting wires or substances to which current may leak. Special precautions of this kind must be taken where sharp angles occur, or where any wires might possibly come in contact with electric light or power wires.

Crosses, when unavoidable, should be made as nearly at right angles as possible.

e. Must be provided with petticoat insulators of glass or porcelain. Porcelain knobs or cleats and rubber hooks will not be approved.

f. Must be so spliced or joined as to be both mechanically and electrically secure without solder. The joints must then be soldered, to insure preservation, and covered with an insulation equal to that on the conductors.

All joints must be soldered, even if made with some form of patent splicing device. This ruling applies to joints and splices in all classes of wiring covered by these rules.

g. Must, where they enter buildings, have drip loops outside, and the holes through which the conductors pass must be bushed with non-combustible, non-absorptive insulating tubes slanting upward toward the inside.

For low-potential systems the service wires may be brought into buildings through a single iron conduit. The conduit to be curved downward at its outer end and carefully sealed to prevent the entrance of moisture. The outer end must be at least one foot from any woodwork, and the inner end must enter a main cut-out cabinet in a manner similar to that described in fine print note under No. 25, Section *b*.

h. Electric light and power wires must not be placed on the same cross-arm with telegraph, telephone, or similar wires, and when placed on the same pole with such wires the distance between the two inside pins of each cross-arm must not be less than twenty-six inches.

i. The metallic sheaths to cables must be permanently and effectively connected to "earth."

GROUND RETURN WIRES

n. For the diminution of electrolytic corrosion of underground metal work, ground return wires must be so arranged that the difference of potential between the grounded dynamo terminal and any point on the return circuit will not exceed twenty-five volts.

It is suggested that the positive pole of the dynamo be connected to the trolley line, and that whenever pipes or other underground metal work are found to be electrically positive to the rails or surrounding earth, that they be connected by conductors arranged so as to prevent as far as possible current flow from the pipes into the ground.

13. Transformers

(*For construction rules, see No.* 62.)

(*See also Nos.* 11, 13 *A and* 36.)

Where transformers are to be connected to high-voltage circuits, it is necessary in many cases, for best protection to life and property, that the secondary system be permanently grounded, and provision should be made for it when the transformers are built.

a. Must not be placed inside of any building, excepting central stations and sub-stations, unless by special permission of the Inspection Department having jurisdiction.

An outside location is always preferable; first, because it keeps the high-voltage primary wires entirely out of the building, and second, for the reasons given in the note to No. 11 *a*.

b. Must not be attached to the outside walls of buildings, unless separated therefrom by substantial supports.

It is recommended that transformers be not attached to frame buildings when any other location is practicable.

13 A. Grounding Low-Potential Circuits

The grounding of low-potential circuits under the followidg regulations is only allowed when such circuits are so arranged that under normal conditions of service there will be no passage of current over the ground wire.

Direct-Current Three-Wire Systems

a. Neutral wire may be grounded and when grounded the following rules must be complied with:

1. Must be grounded at the Central Station on a metal plate buried in coke beneath permanent moisture level, and also through all available underground water and gas pipe systems.

2. In underground systems the neutral wire must also be grounded at each distributing box through the box.

3. In overhead systems the neutral wire must be grounded every 500 feet, as provided in Sections *c*, *e*, *f*, and *g*.

Inspection Departments having jurisdiction may *require* grounding if they deem it necessary.

Two-wire direct-current systems having no accessible neutral point are not to be grounded.

Alternating-Current Secondary Systems

b. Transformer secondaries of distributing systems should preferably be grounded, and when grounded, the following rules must be complied with:

1. The grounding must be made at the neutral point or wire, whenever a neutral point or wire is accesible.

2. When no neutral point or wire is accessible, one side of the secondary circuit may be grounded, provided the maximum difference of potential between the grounded point and any other point in the circuit does not exceed 250 volts.

3. The ground connection must be at the transformer or on the individual service as provided in sections *d*, *e*, *f*, *g*, and when transformers feed systems with a neutral wire, the neutral wire must also be grounded at least every 250 feet for overhead systems, and every 500 feet for underground systems.

Inspection Departments having jurisdiction may *require* grounding if they deem it necessary.

Ground Connections

c. When the ground connection is inside of any building, or the ground wire is inside of or attached to any building (except Central or Sub-Stations), the ground wire must be of copper and have an approved rubber insulating covering, National Electrical Code Standard, for from 0 to 600 volts. (See No. 41.)

d. The ground wire in direct-current three-wire systems must not at Central Stations be smaller than the neutral wire and not smaller than No. 4 B. &. S gage elsewhere.

The ground wire in alternating-current systems must never be less than No. 4 B. & S. gage.

On three-phase system, the ground wire must have a carrying capacity equal to that of any one of the three mains.

e. The ground wire should, except for Central Stations and transformer sub-stations, be kept outside of buildings as far as practicable, but may be directly attached to the building or pole by cleats or straps or on porcelain knobs. Staples must never be used. The wire must be carried in as nearly a straight line as practicable, avoiding kinks, coils, and sharp bends, and must be protected when exposed to mechanical injury.

This protection can be secured by use of an approved molding, and as a rule the ground wire on the outside of a building should be in molding at all places where it is in within seven feet from the ground.

f. The ground connection for Central Stations, transformer substations, and banks of transformers must be made through metal plates buried in coke below permanent moisture level, and connection should

also be made to all available underground piping systems including the lead sheath of underground cables.

g. For individual transformers and building services, the ground connection may be made as in Section *f*, or may be made to water piping systems running into buildings. This connection may be made by carrying the ground wire into the cellar and connecting on the street side of meters, main cocks, etc.

Where it is necessary to run the ground wire through any part of a building it shall be protected by approved porcelain bushings through walls or partitions and shall be run in approved molding, except that in basements it may be supported on porcelain.

In connecting a ground wire to a piping system, the wire should be sweat into a lug attached to an approved clamp, and the clamp firmly bolted to the water pipe after all rust and scale have been removed; or be soldered into a brass plug and the plug forcibly screwed into a pipe-fitting, or, where the pipes are cast iron, into a hole tapped into the pipe itself. For large stations, where connecting to underground pipes with bell and spigot joints, it is well to connect to several lengths, as the pipe joints may be of rather high resistance.

Where ground plates are used, a No. 16 Stubbs' gage copper plate, about three by six feet in size, with about two feet of crushed coke or charcoal, about pea size, both under and over it, would make a ground of sufficient capacity for a moderate-sized station, and would probably answer for the ordinary sub-station or bank of transformers. For a large central station, a plate with considerably more area might be necessary, depending upon the other underground connections available. The ground wire should be riveted to the plate in a number of places, and soldered for its whole length. Perhaps even better than a copper plate is a cast-iron plate with projecting forks, the idea of the fork being to distribute the connection to the ground over a fairly broad area, and to give a large surface contact. The ground wire can probably best be connected to such a cast-iron plate by soldering it into brass plugs screwed into holes tapped in the plate. In all cases, the joint between the plate and the ground wire should be thoroughly protected against corrosion by painting it with waterproof paint or some equivalent.

The details of overhead line work should now be considered and will be discussed under their respective heads:

Spacing and Location of Poles. — As a general rule, the poles should be set from 110 to 120 feet apart. The poles should be located so as to avoid obtrusiveness and to avoid inconvenience to vehicles or pedestrians.

The exact location of each pole in the line work should be determined before any of the poles are set.

Trees should not be used for line supports in lieu of poles, for the reason that the branches of the trees are apt to abraid or injure the wires.

Poles. — The poles should be of selected quality and stock,

of good cedar, or chestnut, and should be sound and free from shakes, checks, or large knots.

The length of the poles would, of course, depend upon conditions. For poles of 25 or 30 feet, the diameter at the smaller end should be not less than 6 inches, and if over 30 feet should be not less than 7 inches.

The poles should all be shaved, housed, and gained, and cleaned ready for painting before erection.

The butt end should be tarred, "carbolined," creosoted, or treated so as to prevent decay.

Gains. — The gains (or the grooves made by the upper end of the poles for the cross-arms) should be about 1½ inches deep, of proper width (usually about 4½ inches), so as to fit the cross-arm exactly, and to be properly squared.

The gains should be painted with a thick coat of lead and oil before fitting the cross-arms to the poles.

Cross-Arms. — The cross-arms should be of No. 1 Michigan or Norway pine, or other equally good wood, suitable for the purpose, thoroughly seasoned and of selected quality.

The cross-arms should be approximately 3½ inches by 4½ inches, and for three pins should be not less than 36 inches long, and for four pins not less than 48 inches long, and of corresponding length for greater number of pins.

The cross-arms should be first painted with two coats of lead; they should then be properly fitted into the gain of the pole and securely fastened in position, using for each pin two iron lag screws about 7 inches long and ⅝ inches diameter. The joints should be made in a substantial manner and so as to leave the cross-arms at right angles to the poles and parallel with each other where two or more arms are used on the same pole.

Pins. — The pins should be of selected locust, or equally good stock about 1½ inches in diameter, and should be fitted closely in the cross-arm and nailed in place.

Insulators. — The insulators for low-potential circuits (such as used in isolated industrial plant work, and for secondary wiring generally) may be of glass, and should preferably be of double "petticoat" type, of suitable size for the wires to be carried by them.

Guard. — Guard irons of suitable form and size should be provided at all turns and corners where necessary to prevent the wires from dropping to the ground, in case they should be detached from the insulator on the cross-arm.

should be so arranged that the conductors may be readily removed and replaced without disturbing the underground conduits or ducts. For this reason, the methods formerly in use, where the conductors were placed in wooden boxes underground, has long since been abandoned, and the conductors are now placed in conduits or ducts. There are several methods now in use which will be worth while considering.

Iron Pipe. — Iron conduit is frequently used for short lengths of small conductors, where only one or two conduits would be required. In such cases, the greater first cost of the iron pipe would be offset by the greater cost of trenching and concrete work required by vitrified ducts or fiber conduit. Of course in cases where iron would be peculiarly subject to corrosion, it would be better to use vitrified conduit, but as a rule, iron pipe, or rather iron conduits, are used for short distances and for small conductors, and where only one or two circuits are to be run in the same trench. Iron conduit is also to be recommended where the ground is liable to "cave in" or settle.

The sizes of conduits and the sizes of conductors which may readily be installed therein and other data relating to iron conduits, are given elsewhere in this book.

While it might be desirable, it is not necessary, however, to lay a bed of concrete for the iron conduits, but where a number of them are run in the same trench it would be better to make a bed of concrete about two inches thick; where fiber conduit or vitrified duct, however, are used, this bed of concrete is absolutely necessary.

Wood Conduits. — This conduit is not now used to any extent, but was formerly used very largely and was sometimes known as "pump log." These conduits are about 8 feet in length and provided with socket joints. They are usually about 4½ inches square outside, with an opening 3 inches in diameter. As this form of conduit is subject to mechanical injury, it is necessary to place them a sufficient distance underground to avoid the possibility of their being disturbed by picks or shovels, or else to provide other means of protection such as placing a wooden plank, etc., over them. These conduits are impregnated with coal tar or similar compound, which acts as a preservative of the wood.

Fiber Conduits. — This is a favorite form of conduit for underground line work. One well-known make of fiber conduit

is manufactured by wrapping wet wood pulp or fiber upon a forming mandril under pressure; after the tube is formed on the mandril it is removed, and after being dried in the air it is placed in a tank of preservative and insulating compound.

Fiber conduits are made in three different styles, namely, the socket-joint type, sleeve-joint type, and the screw-joint type. The screw-joint type is the best, although the sleeve-joint type may be used if care be used when installing it, particularly in making the joints.

In the first-mentioned type, the connections between the lengths of conduit are made by means of male and female joints automatically turned on the end of the conduit and accurately

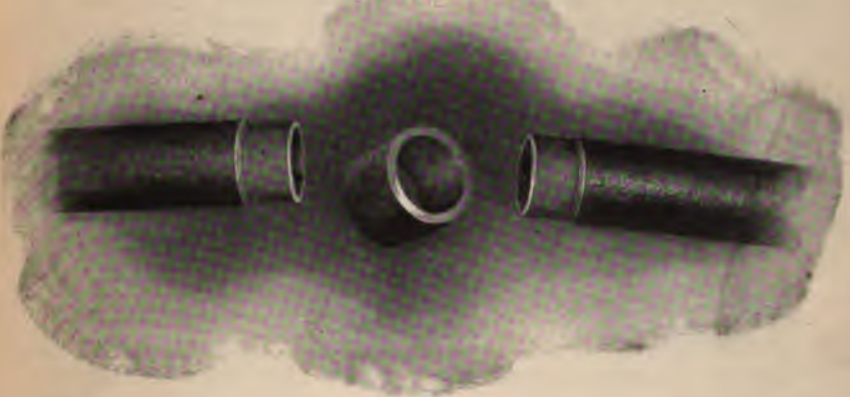


FIG. 89

cut, so that it is only necessary to push one within the other to secure alignment without the use of any sleeve or other device. With this type of conduit, however, it is absolutely necessary that the lengths of conduit should be held rigidly in position, and it is therefore only adapted for use where the conduit is laid in cement.

The second or sleeve-joint type of conduits have the ends of each length turned so that a sleeve may be slipped over the turned portion, and butted up against the shoulder on the tube, and a water-tight connection made. These sleeves are about four inches long and about three-eighths inches in thickness. This type of conduit is shown in Fig. 89.

The screw-joint type of fiber conduit is manufactured with a

slightly thicker wall than the socket-joint type in order to obtain the necessary thickness for cutting the thread on the end of the pipe. The sleeve in this case is threaded, and instead of being slipped on the conduit, as in the case of the sleeve-joint type, it is screwed on, and if desired the thread can be filled with a compound and a water-tight joint obtained. Fig. 90 joints shows screw-joint conduit with the threaded sleeve.

Various fitting curves, elbows, etc., are made for this conduit, including "S" bends, junction boxes, tees, reducers, couplings, elbows, etc. Couplings are also made so that joints may be made between fiber conduit and iron pipe, where for example it may be desired to continue the fiber conduit through the ground and up a pole, where it would be necessary to use iron pipe.

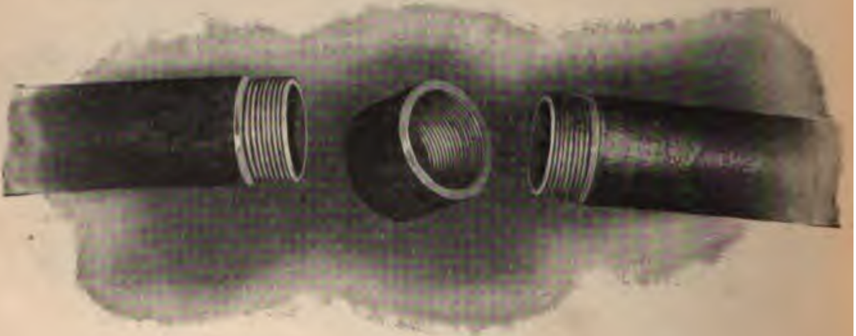


Fig. 90

The advantages of fiber conduit are: Lightness, which reduces the cost of transportation, carting, and handling, therefore making it much cheaper in these respects to iron conduit or vitrified tile. The cost of labor for installing this conduit is less than that of either tile or iron pipe, as cheaper labor can be employed owing to its greater simplicity of construction and erection. It does not corrode or deteriorate like iron pipe, and has a smoother internal surface than vitrified tile. It has insulating qualities; while this advantage should not be considered to any great extent in adopting a form of conduit, yet it does afford a slight additional security in case of break-down of the insulation on the conductor.

The disadvantages of fiber conduit are: It is not strong mechanically; this is of importance where the ground is liable

to "settle" or where a good solid base cannot be provided. It cannot be bent like iron pipe so as to obtain any curvature that may be desired when installing it.

It is strongly recommended that in all cases a concrete bed or matrix, at least two inches, be installed for fiber conduit. If this is not done, there is very great danger of the fiber conduit being broken at the joints. It is also well to flow cement over the top of the conduit as well.

Vitrified Conduit. — Where there are a great number of conductors to be laid in the same trench, this form of conduit is undoubtedly the best that has yet been introduced. Its advantages are that it is cheap in first cost, and after being laid it is practically indestructible, as it is not subject to corrosion or deterioration. It is strong mechanically; it is not combustible, it is an insulator for low potentials, and in the multiple-duct type occupies less space than would be required by the other forms of conduit, which means a reduction in the cost of the concrete bed, the cost of trenching, excavating, etc. It does not require skilled labor to install and it is made in a great variety of forms, sizes, etc.

The conduit is made with single duct, two ducts, three ducts, four ducts, six and nine ducts in multiple. The vitrified conduit is made with square and with round holes. The advantages claimed for the square hole are that the capacity of the square hole is about 25 per cent greater than the round whole duct, particularly where more than one conductor is drawn in a duct. For example, four conductors could be just as readily placed in a square duct as three conductors of the same size in a round duct.

The frictional resistance of the square duct is also less than the round duct, particularly in large sizes of conductors or where two or more conductors are drawn in the same duct.

The relative approximate cost of underground conduits using iron pipe, fiber conduits (seven types) and vitrified conduits, where there are only a few conduits to be installed are roughly as follows (not including trenching or concrete work):—

Iron Pipe, . . .	$1.00
Fiber Conduits . .	60
Vitrified Duct . .	40

Construction of Underground Conduit Systems

The trench for the conduit should be laid out as straight as possible, and for ordinary conditions should be not less than 24 inches between the top of the uppermost conduit and the surface of the ground. After the trench has been prepared, a foundation or bed of concrete of two or three inches should be made of the necessary width for the conduit, and where a complete concrete enclosure is required, the conduit bed should be extended two or three inches on either side. The concrete should be mixed in proportions of one part cement, three parts of sharp sand, and five parts of broken stone or gravel. The broken stone should be of such size as to pass through a one half inch sieve.

Manholes, Handholes, etc. — Manholes or openings should be provided about every 300 feet in order to facilitate the installation of the conductors in the duct. In some cases, where there are sharp bends, they may be located even closer, and in other cases the distances between centers might be increased.

The manholes are usually built of brick or concrete with a cast-iron frame and cover. The manholes are built of various forms — square, round, rectangular and oval, according to conditions. A manhole of the oval type has the advantage that cables can be conveniently arranged around the sides without the possibility of sharp ends, as may occur in the square of rectangular manholes. The manhole cover itself may be of different shape from the manhole, but round or square covers are usually used.

Figures 91 and 92 show two forms of manholes, the former being of the standard type of oval form for a large number of ducts and adapted to withstand heavy traffic, and the latter being a smaller type (square) for a few conduits where the cover would not be subject to heavy loads.

As a rule, manholes should never be less than three feet in diameter, or three feet square. Where there are more than four or five cables, they should be not less than four to five feet in diameter, and four or five feet deep. Manholes should, when possible, be drained to prevent accumulation of water in the bottom from rain, seepage, etc.

Installing Conduit

Iron Pipe. — As already stated, no concrete bed is required for iron pipe, and it should be installed in the same manner as

already described for interior work, except that additional precautions should be taken in the direction of covering the conduit with asphaltum or similar compound to prevent corrosion.

Fiber Conduit. — A concrete bed should be provided for fiber conduit, no matter which type is used. The joints should be carefully dipped or coated with a special liquid compound

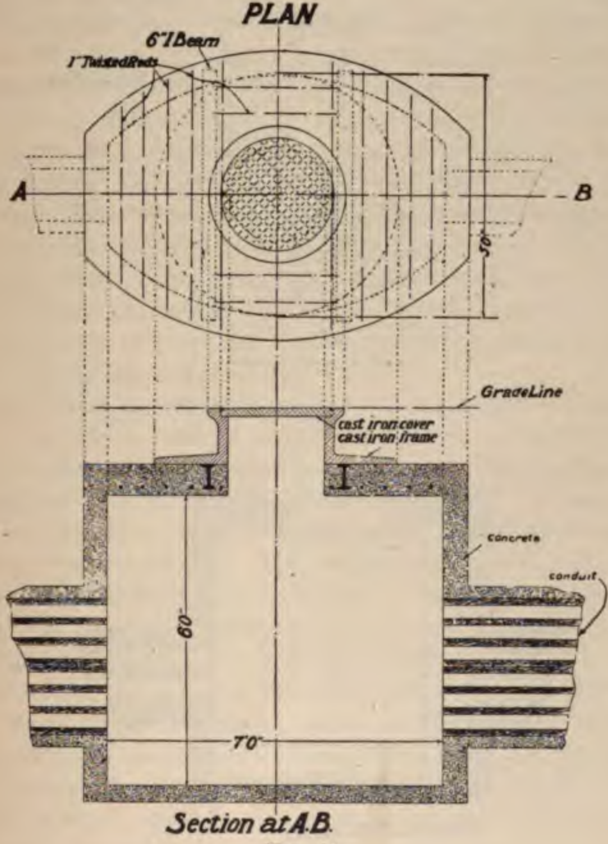


Fig. 91

provided for this purpose, so as to insure water-tight joints. The conduits should be spaced about 1½ inches apart, by means of wooden separators, and the spaces between the ducts and between the walls of the trench and outer ducts should be filled with a thin grouting of cement and sand. If more than one horizontal row of ducts are installed, the grouting of each row

should be smoothed over so as to prepare a base for the next row of ducts. To fish the conductors in fiber conduit, it is not necessary to follow the method of rodding usually required with vitrified conduits, but by utilizing a solid No. 6 iron wire and fishing from one manhole to the next the mandrels and brush may be attached to the end of the wire and pulled through the

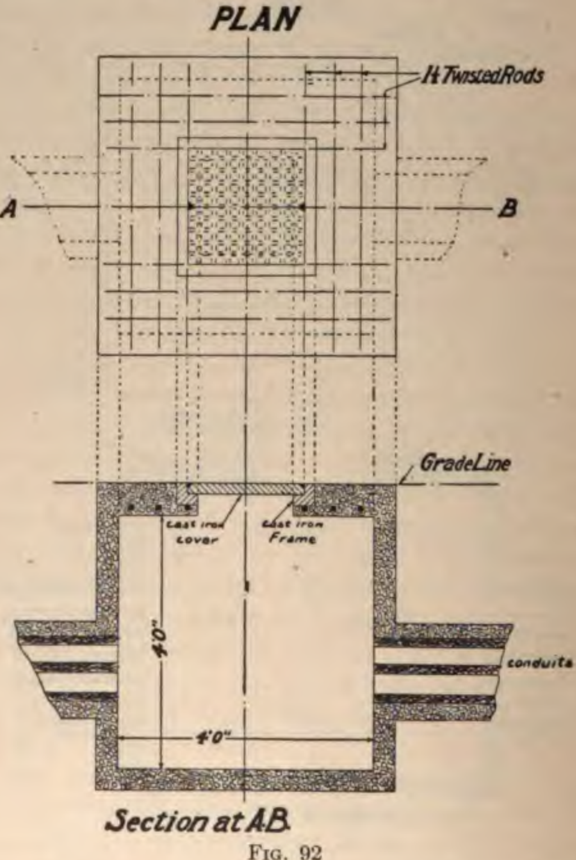


FIG. 92

conduits, thus insuring that the joints are smooth and that there are no obstructions in the conduit. To prevent accidental clogging of the ends of the conduit, wooden plugs should be installed in the openings of all unfinished conduit work, or in all unoccupied conduits at manholes.

Vitrified Tile Conduit. — The following is quoted from Cat-

alogue of the Standard Vitrified Company in relation to the installation of their vitrified conduit.

"**Laying of Conduit.** — When the trench has been properly prepared and the concrete foundation set, the laying of conduit should begin. The ends of the conduit should be butted against the shoulder of the conduit terminal brick; short length should be used for the breaking of joints.

"Care should be taken when each length of conduit is laid that the duct hole is perfectly clear and the conduit level. The work may then proceed, and if the following instructions are carried out no difficulty will be encountered after the ducts are laid. When the first piece of conduit is laid and the keys inserted, one on the top and one on the side of the duct, the burlap for joints should be slipped partly under the conduit and the next piece brought up and wrapped around the conduit. After this operation is completed a thin layer of cement mortar is plastered around the burlap, extending over the edges, so as to cover the scarified portion of the conduit so that it may adhere to it, thus making the joint practically water-tight.

"The burlap should be first prepared in strips of not less than 6 inches in width, and of suitable length to wrap around the conduit, overlapping about 6 inches. If possible the burlap should be saturated in asphaltum or pitch, but if this is not convenient it may be dipped in water so as to stick to the conduit until the joint has been cemented. The engineer or foreman in charge should personally oversee the making of the joint, and especially see that the keys are inserted, as in many instances they are left out by the workmen, causing considerable trouble and expense. Sufficient time should be allowed for the joints to harden.

"After the ducts are laid the sides are filled in with either concrete or dirt, as specified, care being taken that the conduits are not forced out of alignment by the careless filling in of the sides. The top layer of concrete may then be laid and leveled. After this the trench is ready for filling in.

"In the laying of the self-centering single-duct conduit no dowel pins are used, the ducts being self-centering — one piece of conduit socketing into the other. Burlaping and cementing of joint is not necessary. Otherwise the instructions for the laying of multiple duct should be followed. The use of a mandrel in laying the self-centering conduit is superfluous.

"As each section of the system, that is from manhole to man-

hole, is completed, it should be rodded to insure the duct being clear. For this purpose wooden rods are employed, the rods being from 3 to 4 feet long by one inch in diameter, and provided with brass couplings on the ends. The first rod is pushed into the duct chamber, the second one is then attached, and then the third and so on, until the first rod appears in the manhole on the opposite end.

"A wooden mandrel about 10 inches long, made to conform to the shape of the duct, but about ¼-inch smaller in diameter, is attached to the last rod, and a galvanized iron wire is then attached to the other end of mandrel. The rods are drawn through the duct and uncoupled until the mandrel has passed through the ducts. The wire is left remaining in the chamber and secured in the manhole to prevent its being pulled out. The same operation is repeated until all the ducts are tested and wired. Should obstructions be met with and the mandrel bind, the location of the obstructions may be easily ascertained by the length of rod yet remaining in the duct, and may be easily removed. This method is far better than pulling the mandrel through as the ducts are laid, as in many cases the duct is obstructed or thrown out of alignment, by the filling in of the concrete or trench, and this would not be noticed until an attempt was made to draw the cable; the wire left in the duct being used in drawing the cables."

Drawing in the Cables

After the conduits have been tested by means of the mandrel to ascertain that they are continuous, and that the joints are smooth, the work of installing the cables may be started. Special precaution should be taken to prevent bending the cables sharply so as to avoid injuring the lead sheathing or the rubber insulation.

If the cable is light and of small diameter, and the distance is not over 300 feet and the run fairly straight, it can usually be pulled in by hand, but often other means must be provided so as to secure sufficient power. Precautions should be taken, however, to avoid placing too great a strain on the cables, as it is liable to injure them, and the injuries may not show up immediately, but may cause trouble later. The remedy is to avoid placing the manholes too far apart, and to have the runs as straight as possible, and to properly test the conduits for continuity and smoothness before starting to install the cables.

Enough slack should be left in each manhole to allow the cables to pass close to the side walls of the manhole, and to have the center free and accessible for a man to enter the manhole. Where there are a great number of cables in a manhole, shelves or other supports should be provided for holding the cables apart and in position. Where two or more conductors are placed in the same duct, they should always be pulled in at the same time, for otherwise the cables last pulled in are apt to injure those already installed.

The following tables give various data relating to single-conductor and three-conductor rubber-insulated lead-covered cables. These tables are taken from the catalogue of the Fiber Conduit Company, and are from data furnished by the Standard Underground Cable Company.

APPENDIX

Sizes of Conduits Required for Various Sizes of Conductors

As probably 80 per cent of interior wiring at the present day is done according to the conduit system, the problem of selecting the proper size of conduit for the conductors to be installed therein is very important. Figs. 93 to 119 show various sizes of conduits and sizes of conductors which may be installed therein.

Two types of conduits are shown, namely, the lined (such as manufactured by the Sprague Company), and the unlined (such as loricated electro duct and similar enameled conduits). The dimensions of conduits given in the figures are inside measurements. The sizes of conduits range from $\frac{1}{2}$ inch to 3 inches in the unlined type, and from $\frac{7}{16}$ inch to $2\frac{3}{4}$ inches in the lined type. The sizes of conductors shown vary from No. 14 B. & S. gage to 2,000,000 circular mils. In addition to electric light conductors, cables made up of telephone and bell wire are also shown.

It will be noticed in some cases that the same sizes and numbers of conductors are shown in two different sizes of conduits. In all cases, the larger size of conduit should be used, except for straight runs having no elbows or bends whatever, or for short vertical runs without elbows, in which cases the smaller sizes of conduit may sometimes be used. In long runs, having a number of bends or turns, even larger sizes of conduits than those shown should be used. The figures show the amount of space around the conductors, and judgment should, of course, be exercised in selection of conduits in all cases. The conductors shown in the figures are insulated according to the rules of the National Board of Fire Underwriters. The thickness of the rubber wall for the various sizes of conductors are as follows:

From No. 14 to No. 8 B. &. S. G., $\frac{3}{64}$ inches
6 to No. 2 B. & S. G., $\frac{1}{16}$ "
1 to No. 4-0 B. & S. G., $\frac{5}{64}$ "
4-0 to 500,00 c.m $\frac{3}{32}$ "
500,000 to 1,000,000 c.m, $\frac{7}{64}$ "
1,000,000 to 2,000,000 c.m. $\frac{1}{8}$ "

The sizes of the various conductors used in the figures, the strands of which they are composed, and the outside diameter over the braid, are given in the Table of Diameters in the chapter on "Conductors."

N.B. — It must be remembered that for the lined type of conduit, conductors having single outside braid only are required, but for the unlined conduit a conductor having a double braid must be used. The diameters of conductors shown, are based on this rule.

FIG. 93

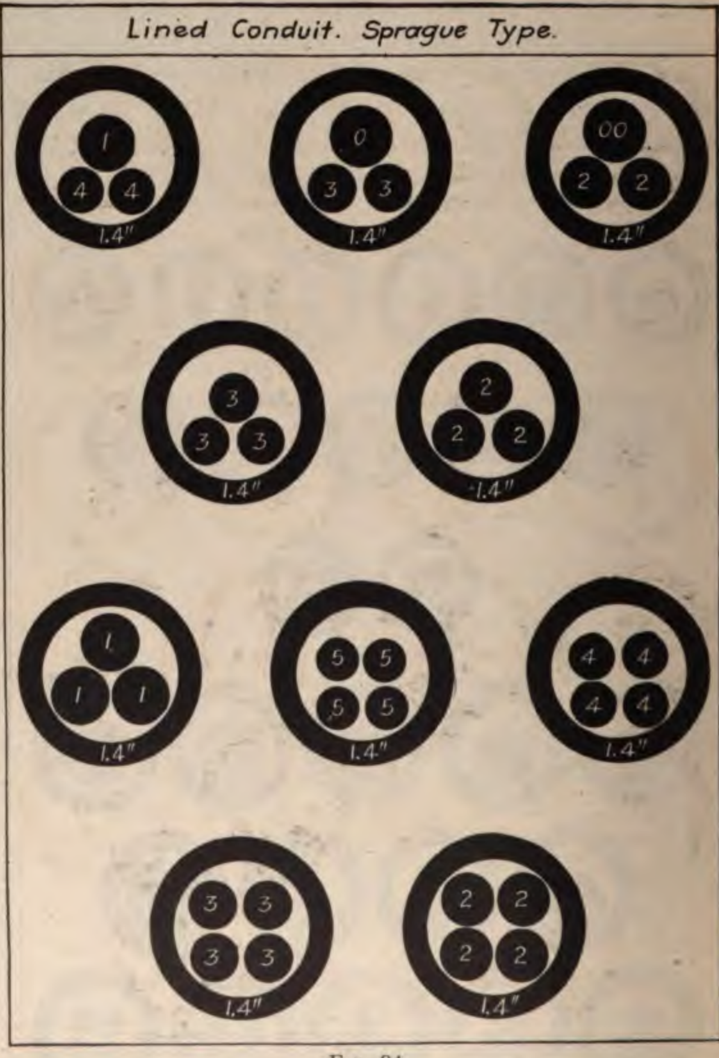

Lined Conduit. Sprague Type.
1
4 4
1.4"
0
3 3
1.4"
00
2 2
1.4"
3
3 3
1.4"
2
2 2
1.4"
1
1 1
1.4"
5 5
5 5
1.4"
4 4
4 4
1.4"
3 3
3 3
1.4"
2 2
2 2
1.4"

Fig. 94


Lined Conduit. Sprague Type
0000
1¼"
250,000 c.m.
1¼"
300,000
1¼"
350,000
1¼"
400,000
1¼"
10 Pairs
1¼"
15 Pairs
1¼"
20 Pairs
1¼"
5 5
1¼"
4 4
1¼"
3 3
1¼"
2 2
1¼"
4 6 6
1¼"
2 5 5
1¼"
1 4 4
1¼"
6 6 6
1¼"
5 5 5
1¼"
4 4 4
1¼"
3 3 3
1¼"
8 8 8 8
1¼"
6 6 6 6
1¼"
5 5 5 5
1¼"

Fig. 95

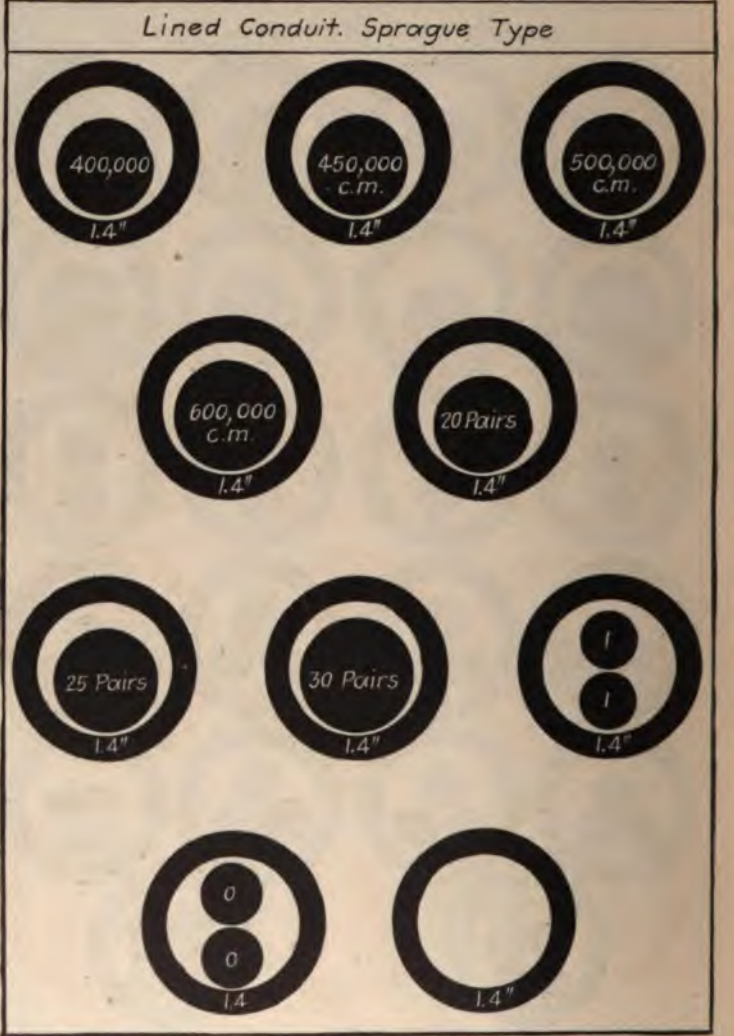

Lined Conduit. Sprague Type
400,000
1.4"
450,000
c.m.
1.4"
500,000
c.m.
1.4"
600,000
c.m.
1.4"
20 Pairs
1.4"
25 Pairs
1.4"
30 Pairs
1.4"
1
1
1.4"
0
0
1.4
1.4"

FIG. 96

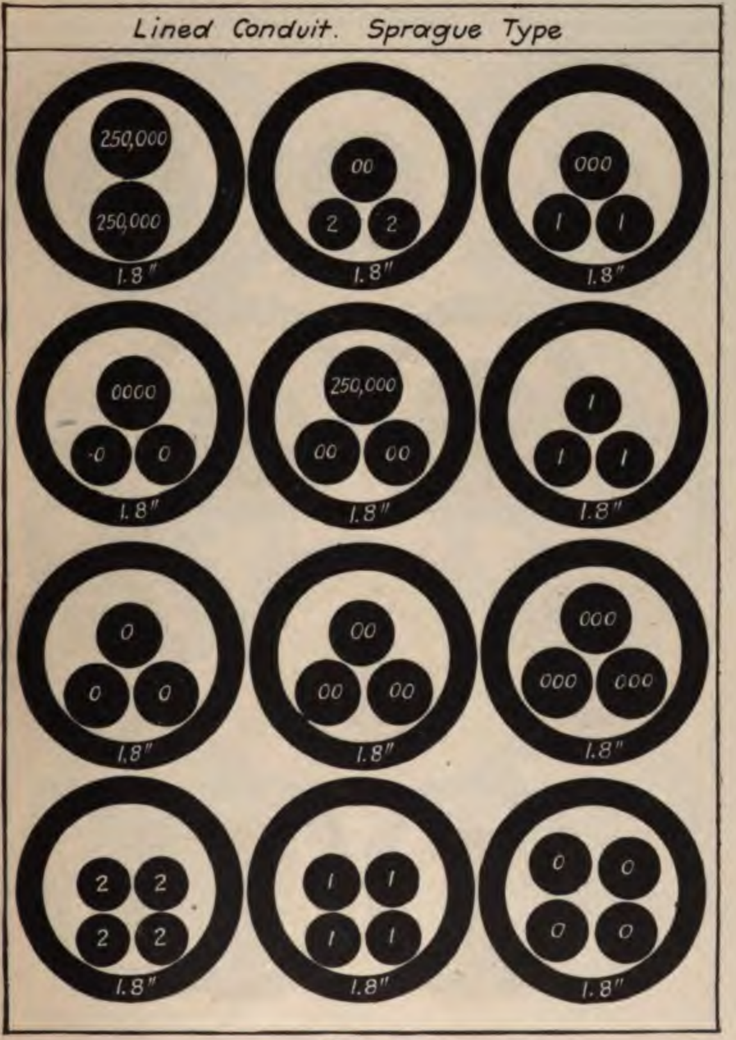

Lined Conduit. Sprague Type
250,000
250,000
1.8″
00
2
2
1.8″
000
1
1
1.8″
0000
0
0
1.8″
250,000
00
00
1.8″
1
1
1
1.8″
0
0
0
1.8″
00
00
00
1.8″
000
000
000
1.8″
2
2
2
2
1.8″
1
1
1
1
1.8″
0
0
0
0
1.8″

Fig. 97


Lined Conduit. Sprague Type.
600,000
1.8"
700,000
1.8"
800,000
1.8"
900,000
1.8"
30 Pairs
1.8"
40 Pairs
1.8"
0
0
1.8"
00
00
1.8"
000
000
1.8"
0000
0000
1.8"

Fig. 98

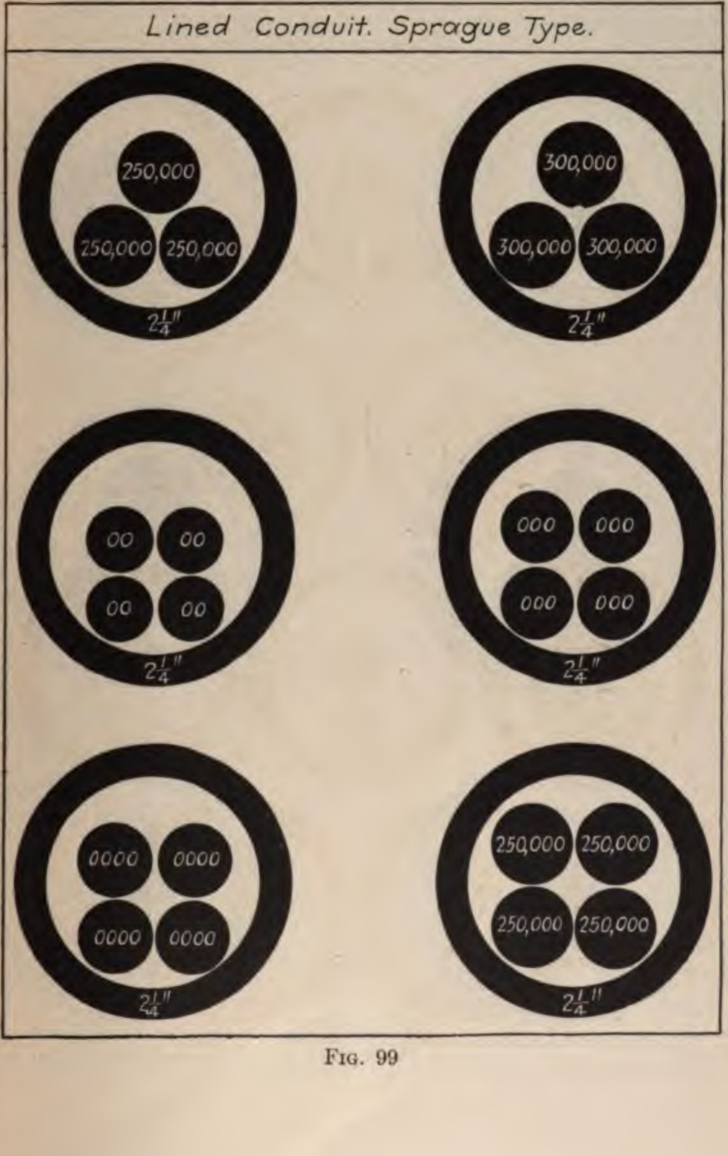

Lined Conduit. Sprague Type.
250,000
250,000
250,000
$2\frac{1}{4}''$
300,000
300,000
300,000
$2\frac{1}{4}''$
00
00
00
00
$2\frac{1}{4}''$
000
000
000
000
$2\frac{1}{4}''$
0000
0000
0000
0000
$2\frac{1}{4}''$
250,000
250,000
250,000
250,000
$2\frac{1}{4}''$

Fig. 99

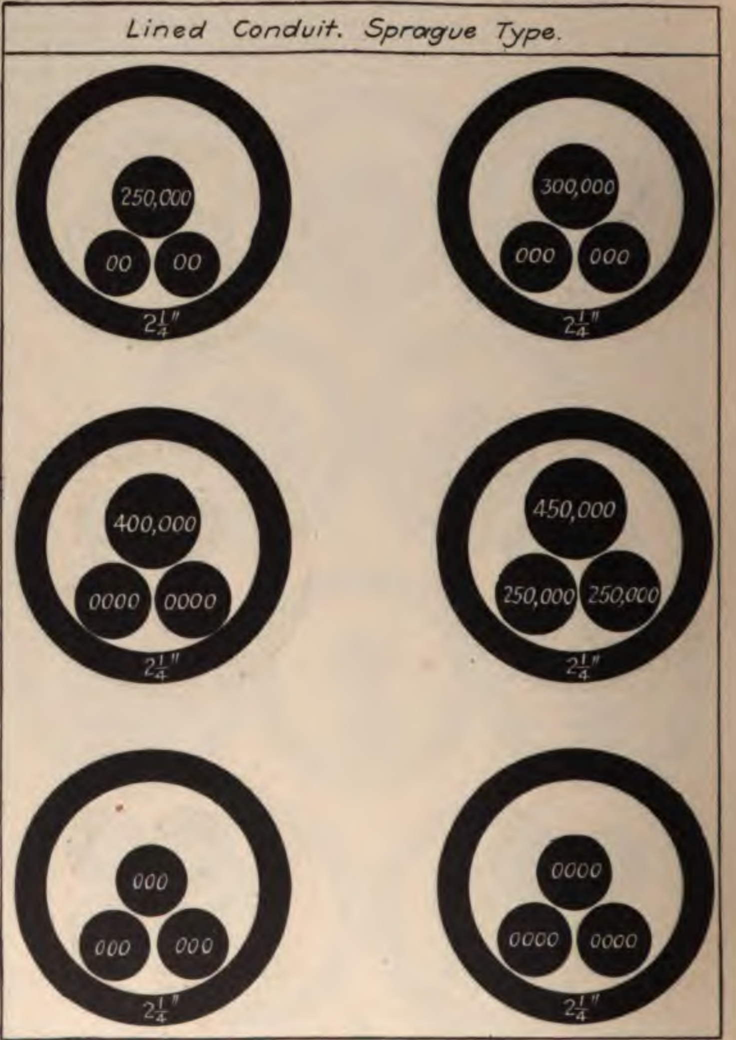

Lined Conduit. Sprague Type.
250,000
00
00
2¼"
300,000
000
000
2¼"
400,000
0000
0000
2¼"
450,000
250,000
250,000
2¼"
000
000
000
2¼"
0000
0000
0000
2¼"

Fig. 100

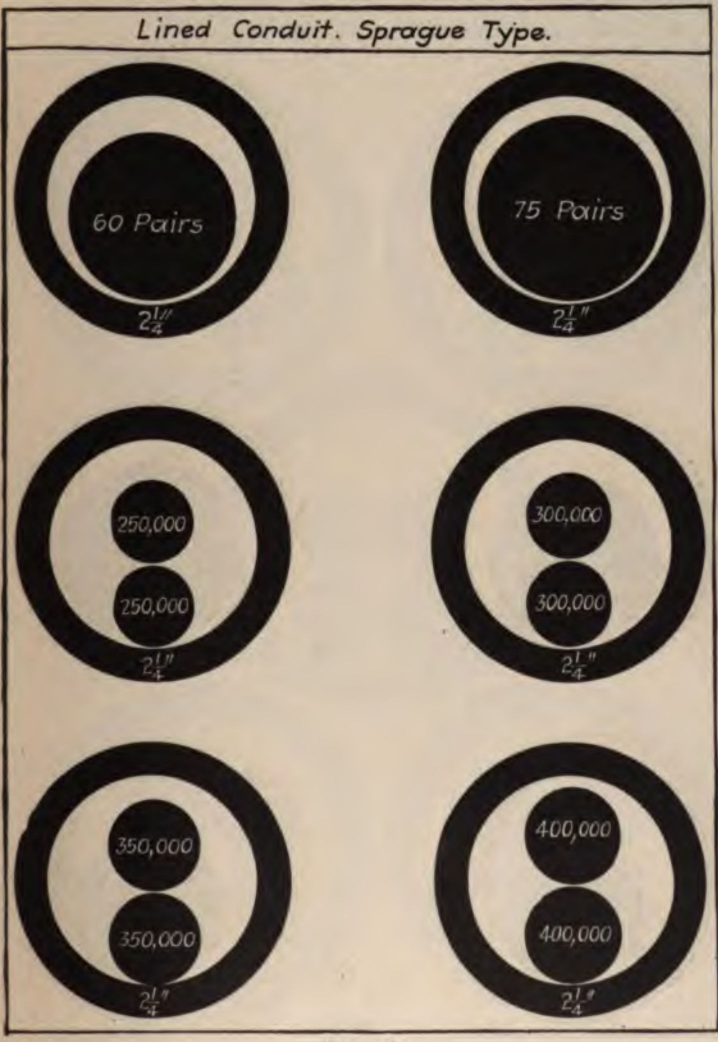

Lined Conduit. Sprague Type.
60 Pairs
$2\frac{1}{4}''$
75 Pairs
$2\frac{1}{4}''$
250,000
250,000
$2\frac{1}{4}''$
300,000
300,000
$2\frac{1}{4}''$
350,000
350,000
$2\frac{1}{4}''$
400,000
400,000
$2\frac{1}{4}''$

Fig. 101


Lined Conduit. Sprague Type.
900,000
$2\frac{1}{4}''$
1,000,000
$2\frac{1}{4}''$
1,500,000
$2\frac{1}{4}''$
1,800,000
$2\frac{1}{4}''$
40 Pairs
$2\frac{1}{4}''$
50 Pairs
$2\frac{1}{4}''$

Fig. 102

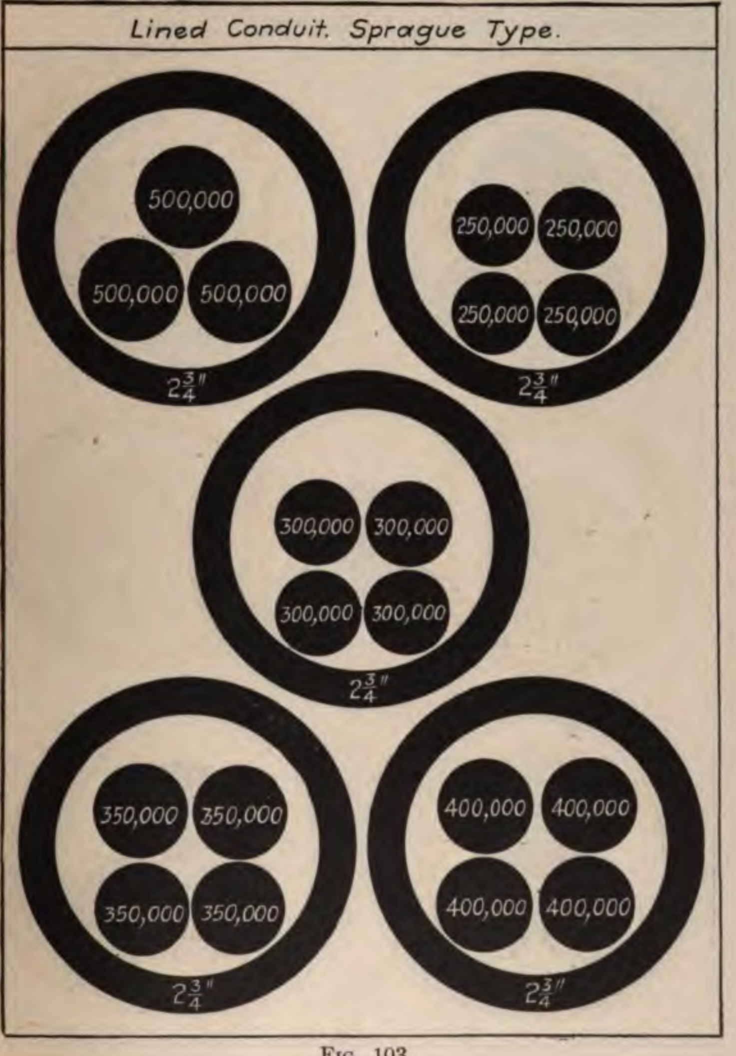

Lined Conduit. Sprague Type.
500,000
500,000
500,000
2¾″
250,000
250,000
250,000
250,000
2¾″
300,000
300,000
300,000
300,000
2¾″
350,000
350,000
350,000
350,000
2¾″
400,000
400,000
400,000
400,000
2¾″

FIG. 103

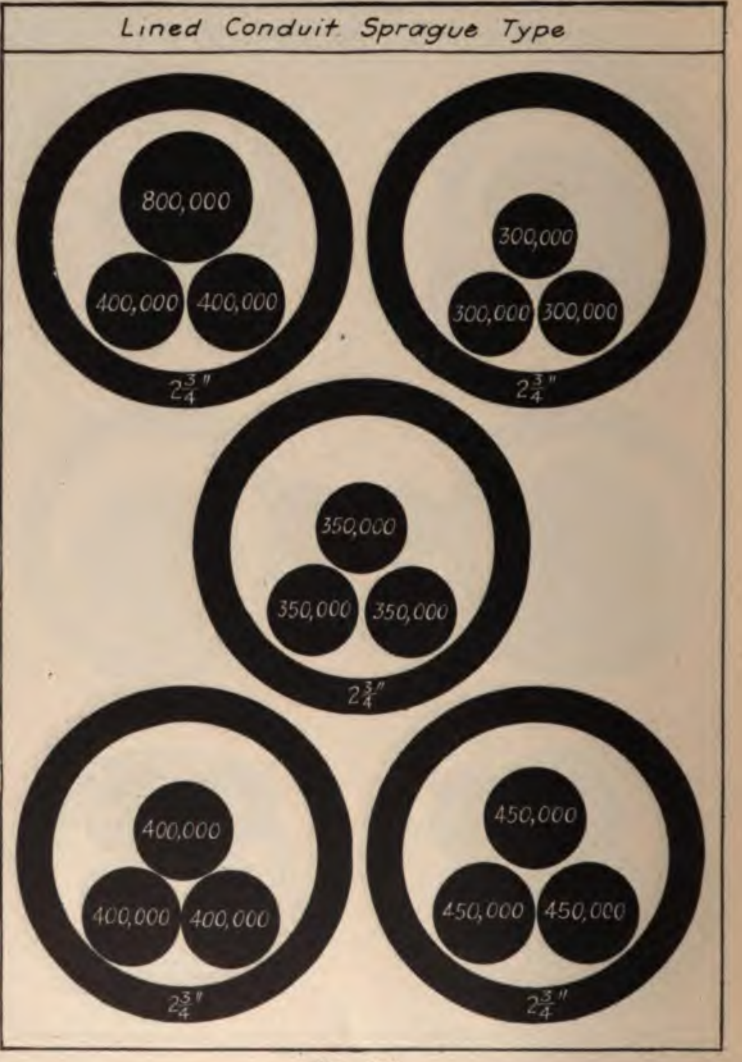

Lined Conduit Sprague Type
800,000
400,000
400,000
2¾"
300,000
300,000
300,000
2¾"
350,000
350,000
350,000
2¾"
400,000
400,000
400,000
2¾"
450,000
450,000
450,000
2¾"

Fig. 104

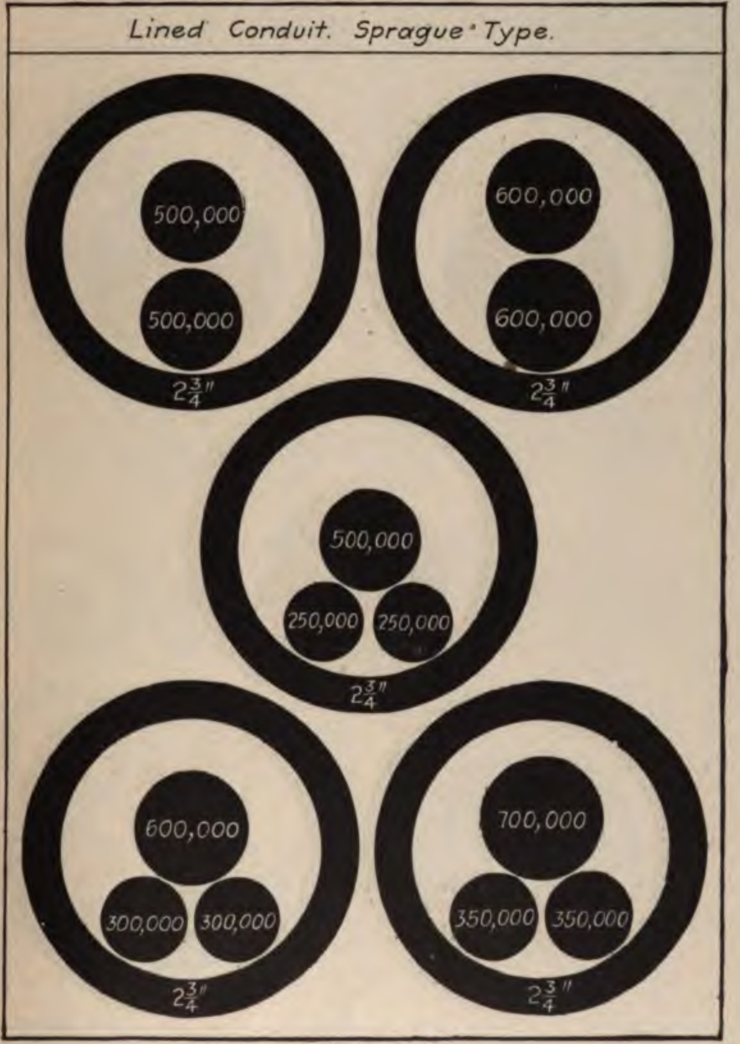

Lined Conduit. Sprague Type.
500,000
500,000
2¾″
600,000
600,000
2¾″
500,000
250,000
250,000
2¾″
600,000
300,000
300,000
2¾″
700,000
350,000
350,000
2¾″

Fig. 105

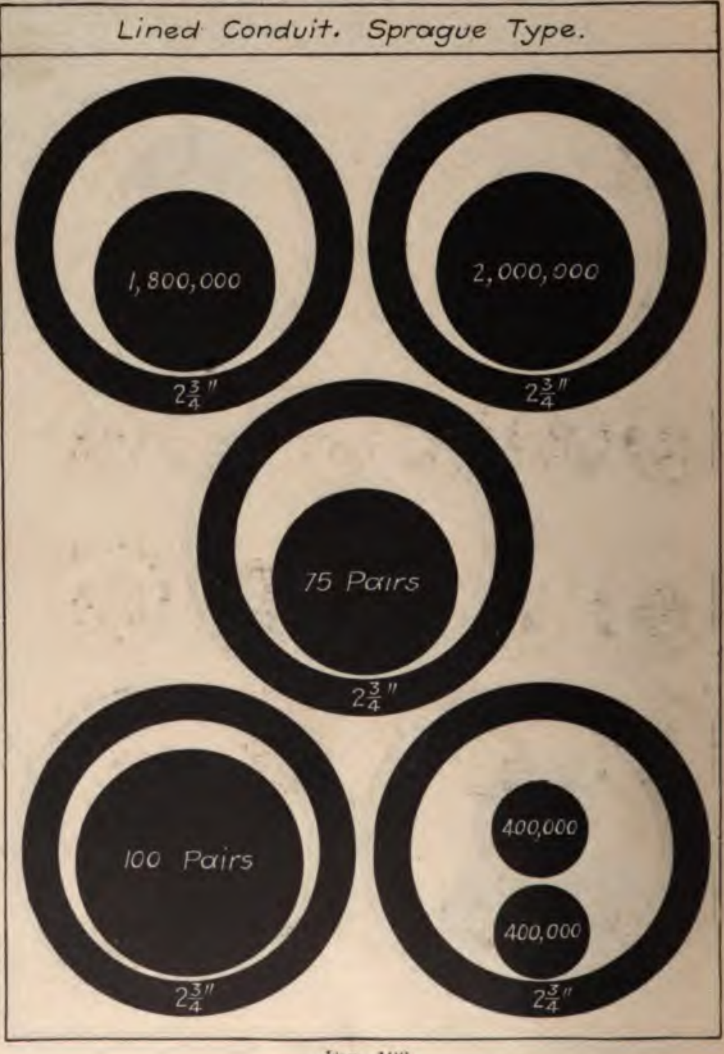

Lined Conduit. Sprague Type.
1,800,000
$2\frac{3}{4}''$
2,000,000
$2\frac{3}{4}''$
75 Pairs
$2\frac{3}{4}''$
100 Pairs
$2\frac{3}{4}''$
400,000
400,000
$2\frac{3}{4}''$

Fig. 106

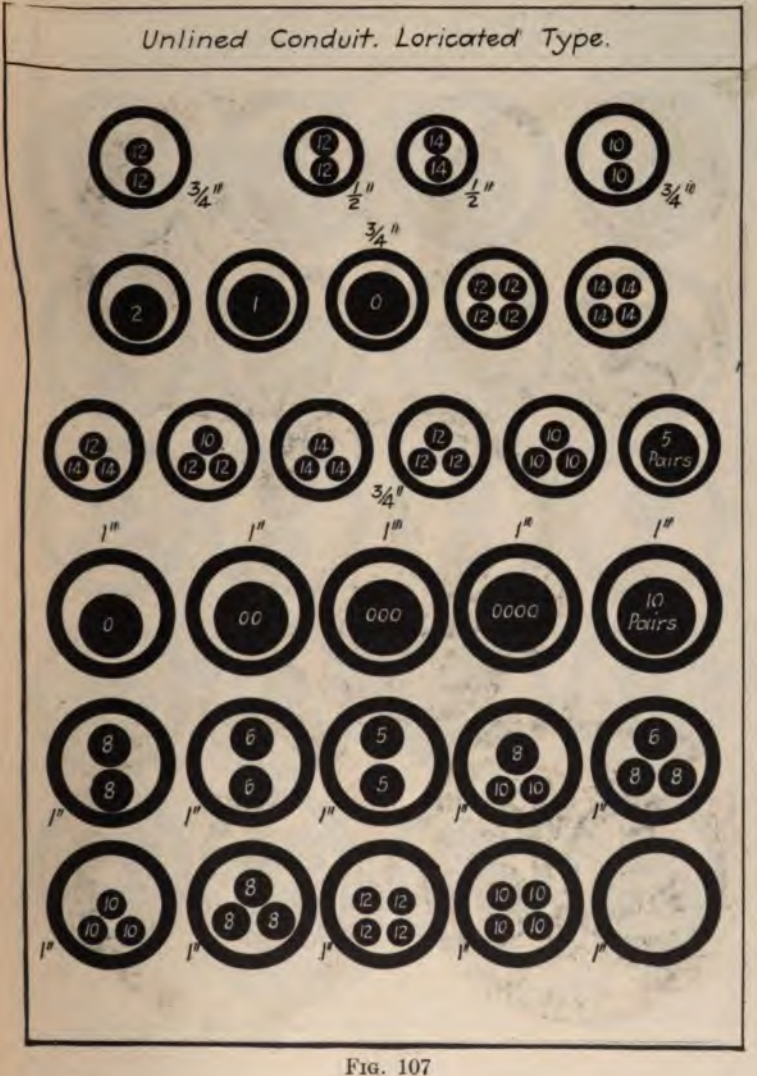

Unlined Conduit. Loricated Type.
12 12 3/4"
12 12 1/2"
14 14 1/2"
10 10 3/4"
3/4"
2
1
0
12 12 12 12
14 14 14 14
12 14 14
10 12 12
14 14 14
12 12 12
10 10 10
5 Pairs
3/4"
1"
0
00
000
0000
10 Pairs
8 8
6 6
5 5
8 10 10
6 8 8
10 10 10
8 8 8
12 12 12 12
10 10 10 10

Fig. 107

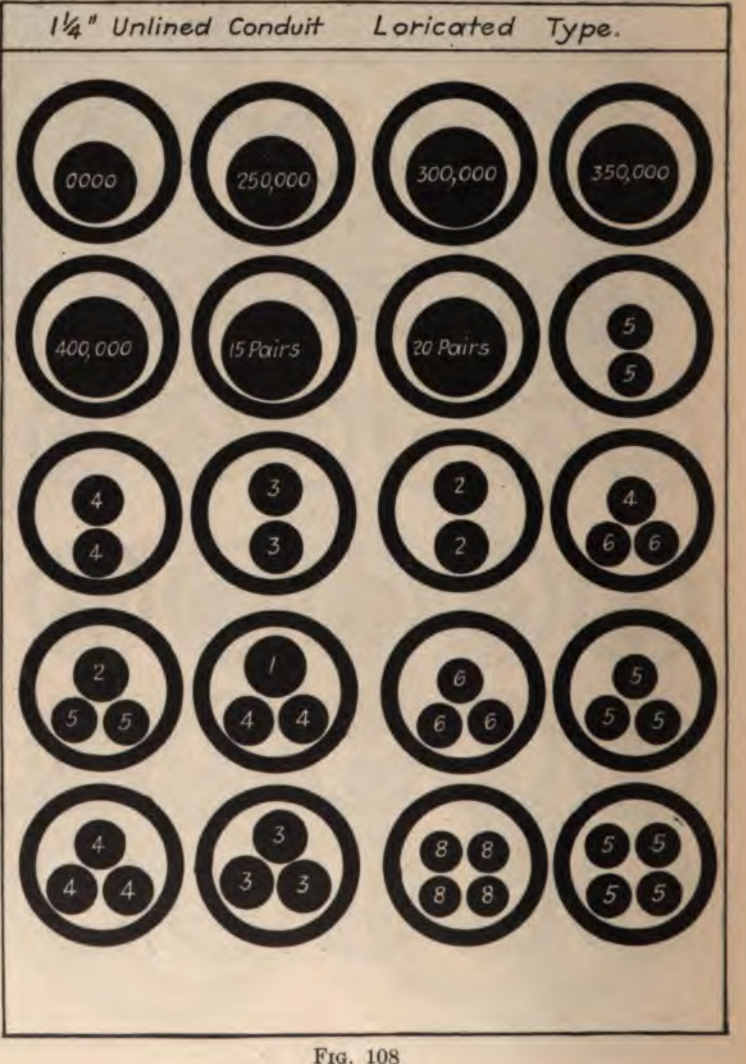

1¼" Unlined Conduit Loricated Type.
0000
250,000
300,000
350,000
400,000
15 Pairs
20 Pairs
5
5
4
4
3
3
2
2
4
6
6
2
5
5
1
4
4
6
6
6
5
5
5
4
4
4
3
3
3
8
8
8
8
5
5
5
5

FIG. 108

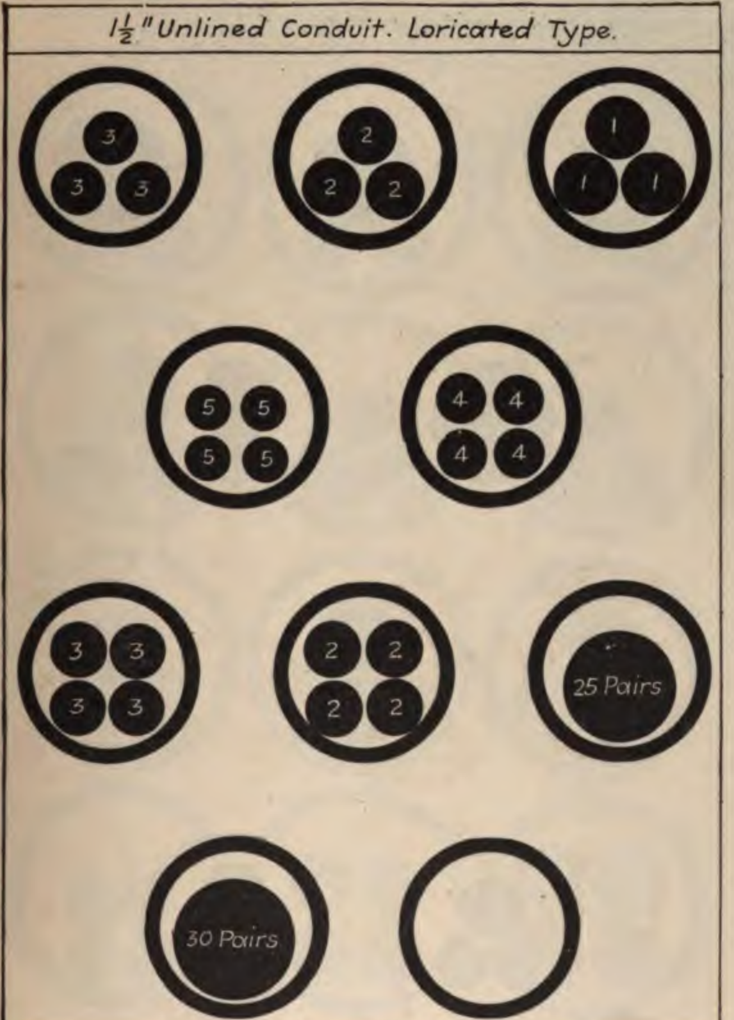

1½" Unlined Conduit. Loricated Type.
3
3 3
2
2 2
1
1 1
5 5
5 5
4 4
4 4
3 3
3 3
2 2
2 2
25 Pairs
30 Pairs

Fig. 109

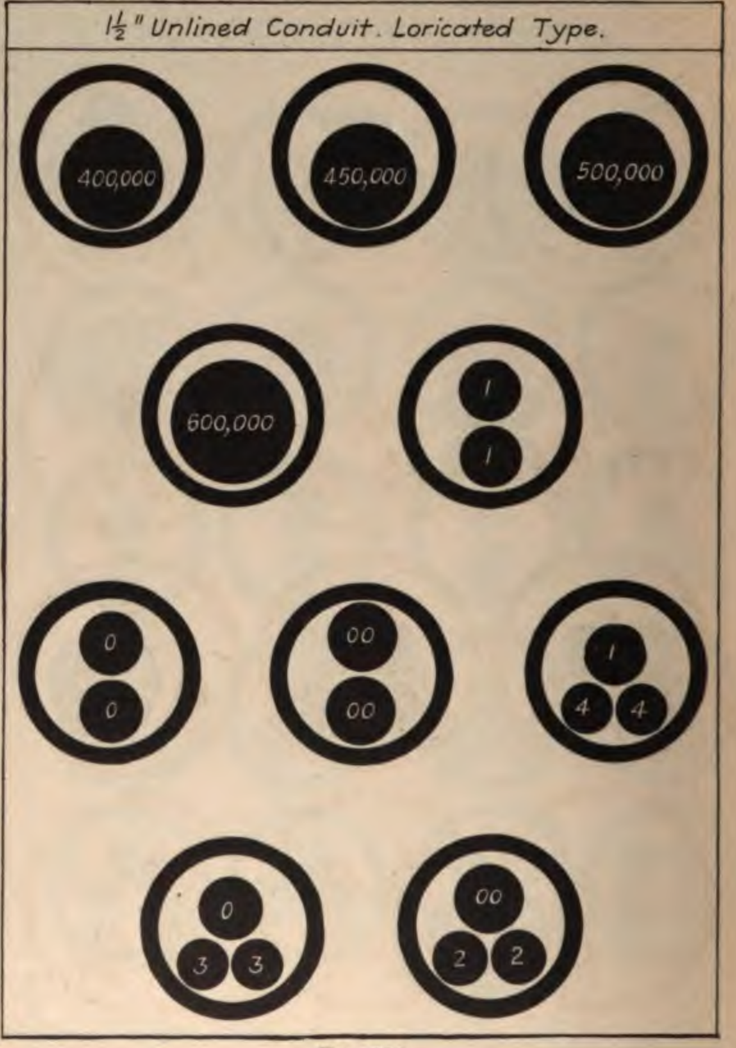

1½" Unlined Conduit. Loricated Type.
400,000
450,000
500,000
600,000
1
1
0
0
00
00
1
4
4
0
3
3
00
2
2

Fig. 110

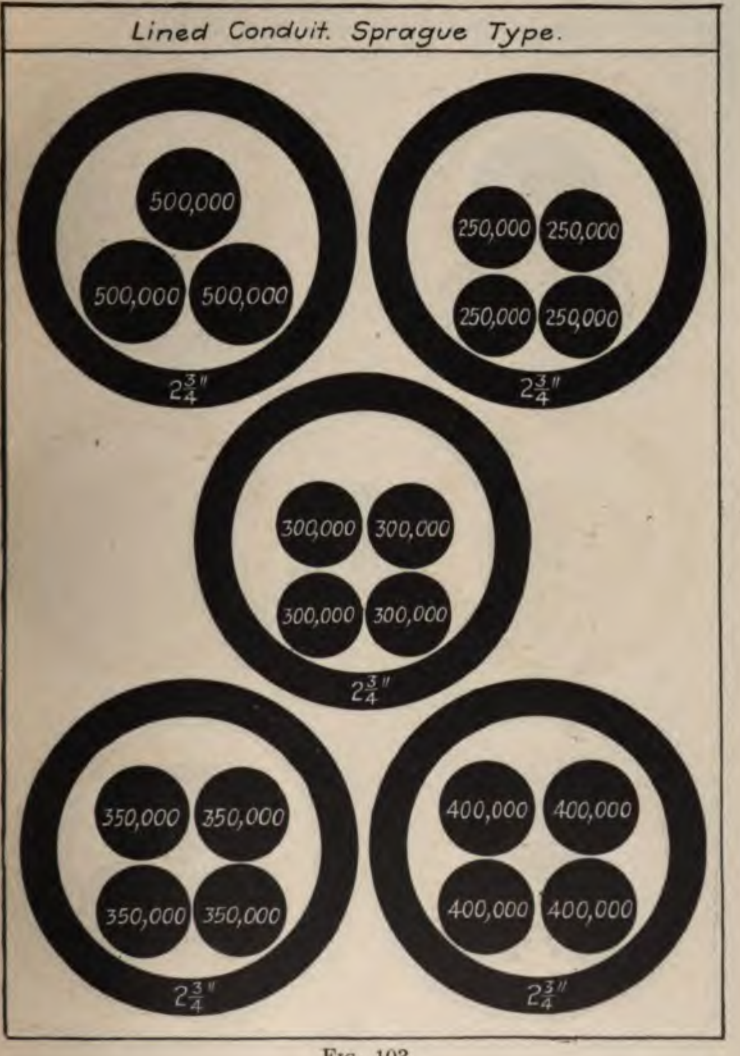

Lined Conduit. Sprague Type.
500,000
500,000
500,000
2¾"
250,000
250,000
250,000
250,000
2¾"
300,000
300,000
300,000
300,000
2¾"
350,000
350,000
350,000
350,000
2¾"
400,000
400,000
400,000
400,000
2¾"

FIG. 103

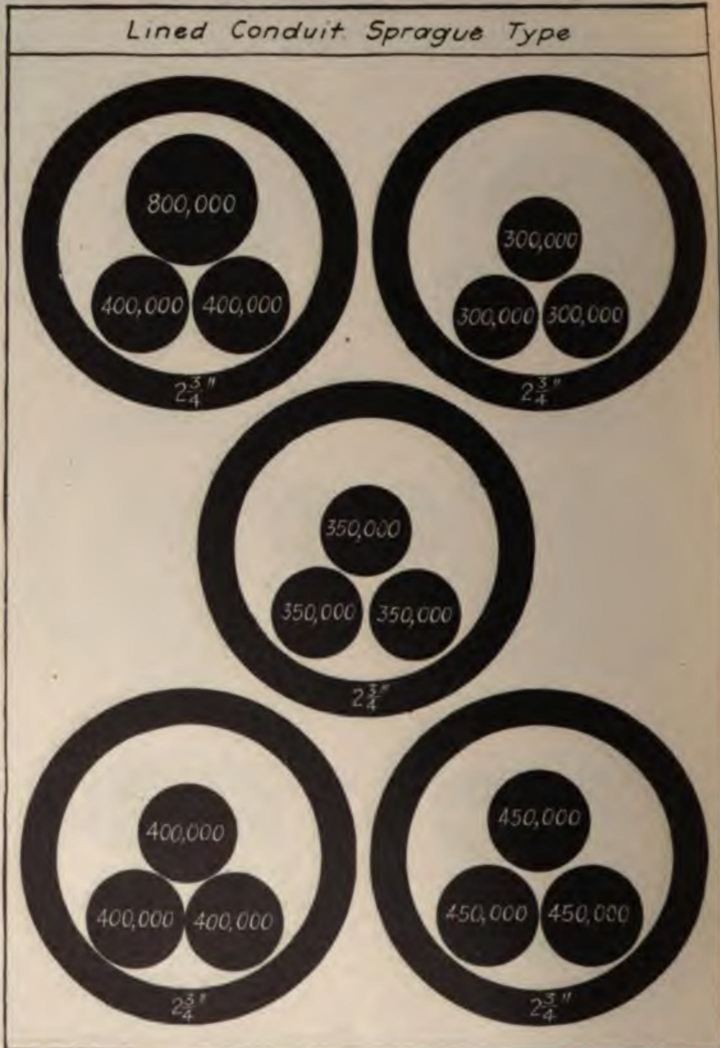

Lined Conduit Sprague Type
800,000
400,000
400,000
$2\frac{3}{4}''$
300,000
300,000
300,000
$2\frac{3}{4}''$
350,000
350,000
350,000
$2\frac{3}{4}''$
400,000
400,000
400,000
$2\frac{3}{4}''$
450,000
450,000
450,000
$2\frac{3}{4}''$

Fig. 104

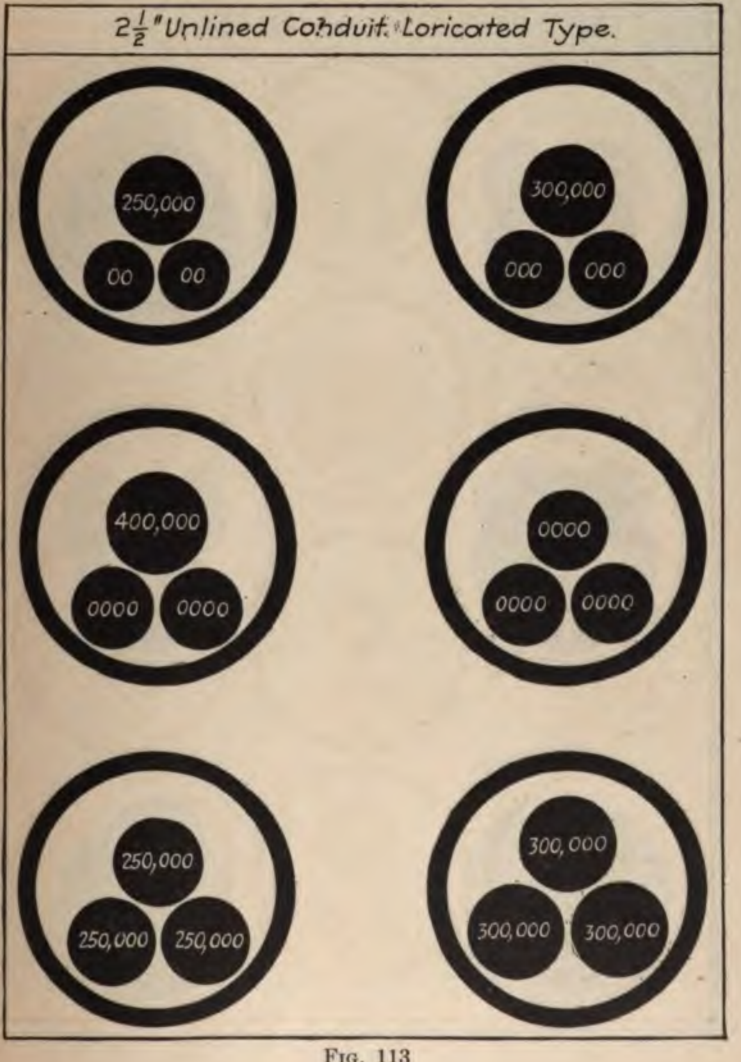

2½" Unlined Conduit. Loricated Type.
250,000
00
00
300,000
000
000
400,000
0000
0000
0000
0000
0000
250,000
250,000
250,000
300,000
300,000
300,000

FIG. 113

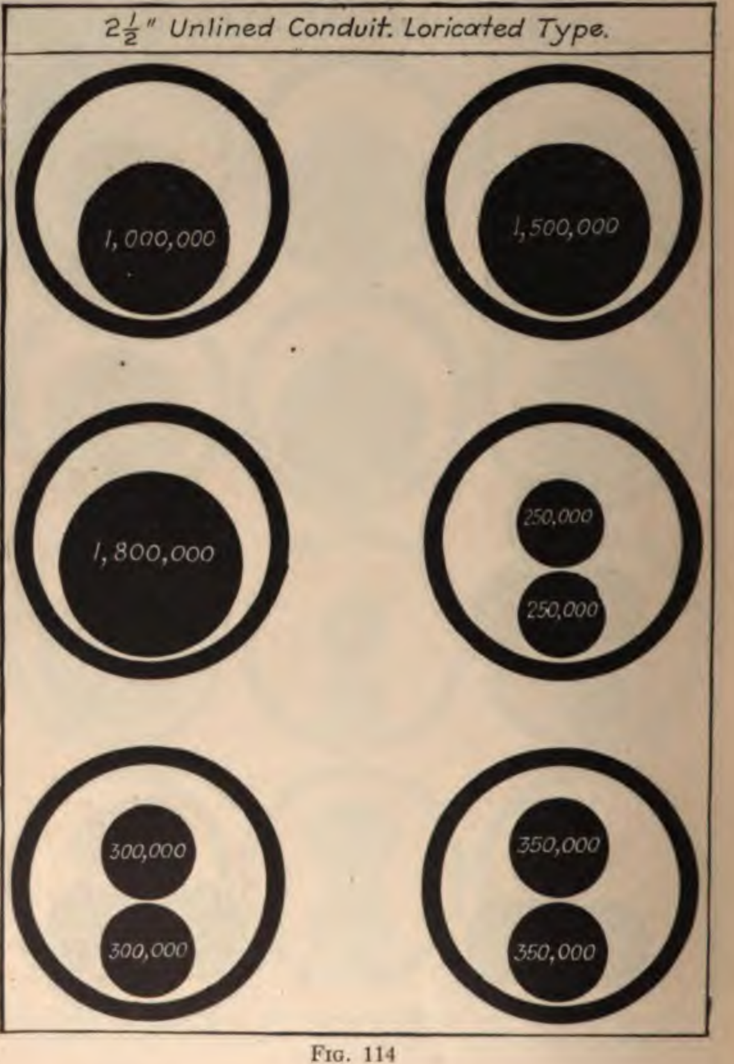

2½" Unlined Conduit. Loricated Type.
1,000,000
1,500,000
1,800,000
250,000
250,000
300,000
300,000
350,000
350,000

Fig. 114

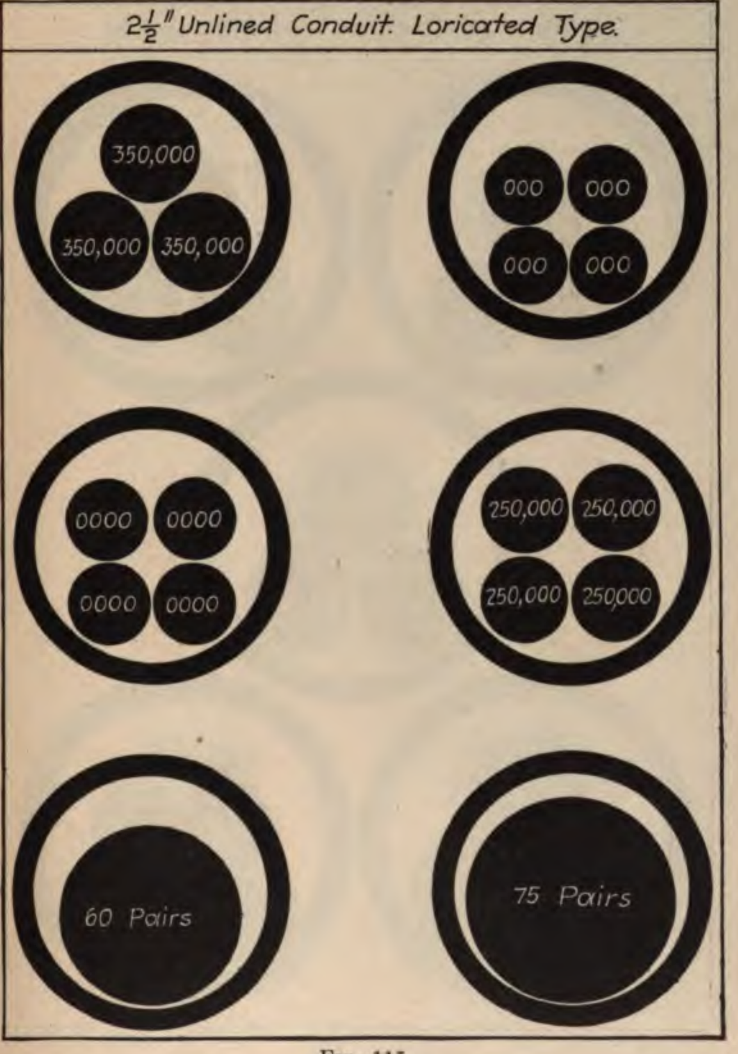

2½" Unlined Conduit. Loricated Type.
350,000
350,000
350,000
000
000
000
000
0000
0000
0000
0000
250,000
250,000
250,000
250,000
60 Pairs
75 Pairs

FIG. 115

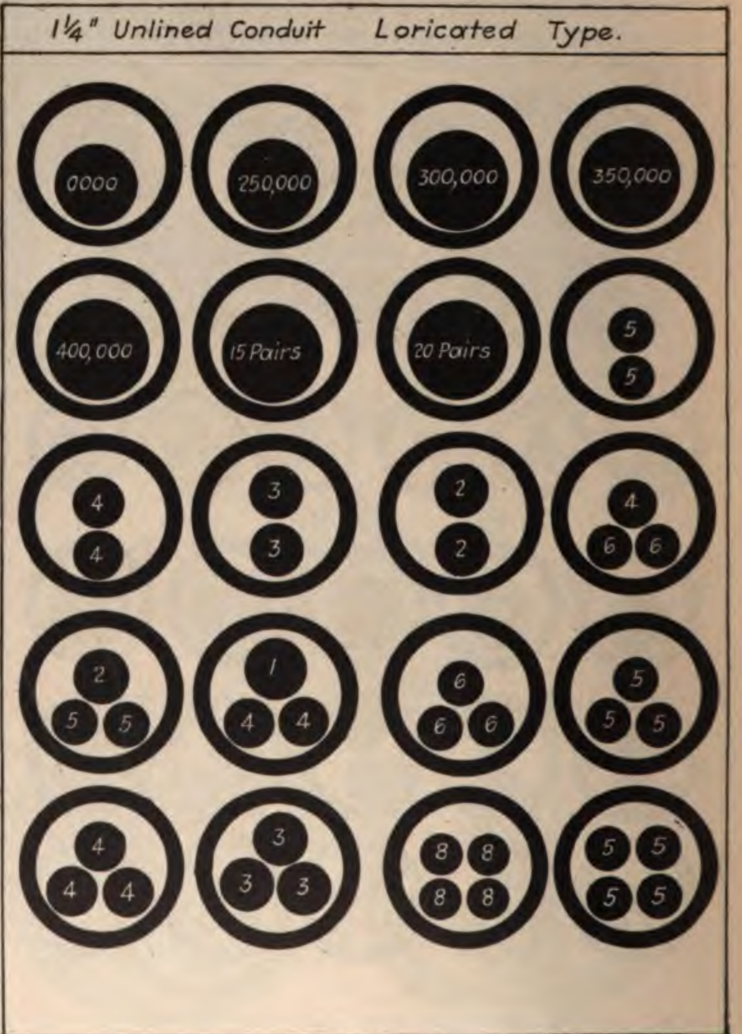

1¼" Unlined Conduit Loricated Type.
0000
250,000
300,000
350,000
400,000
15 Pairs
20 Pairs
5
5
4
4
3
3
2
2
4
6 6
2
5 5
1
4 4
6
6 6
5
5 5
4
4 4
3
3 3
8 8
8 8
5 5
5 5

Fig. 108

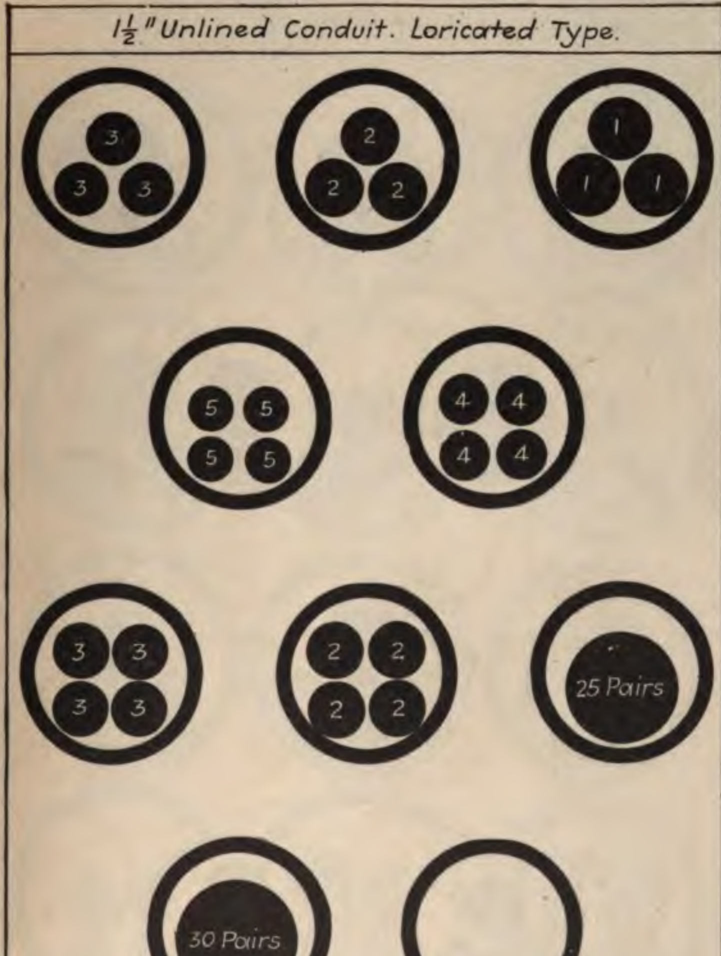
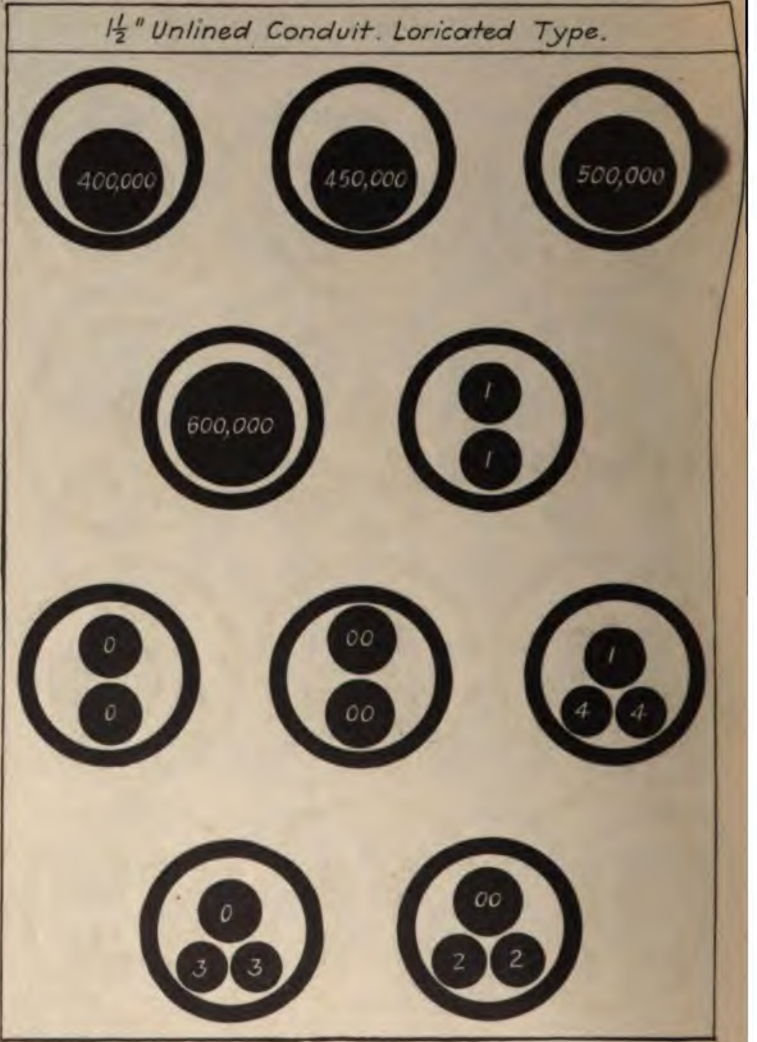

1½" Unlined Conduit. Loricated Type.
3
3
3
2
2
2
1
1
1
5
5
5
5
4
4
4
4
3
3
3
3
2
2
2
2
25 Pairs
30 Pairs

FIG. 109



1½" Unlined Conduit. Loricated Type.
400,000
450,000
500,000
600,000
1
1
0
0
00
00
1
4
4
0
3
3
00
2
2

FIG. 110

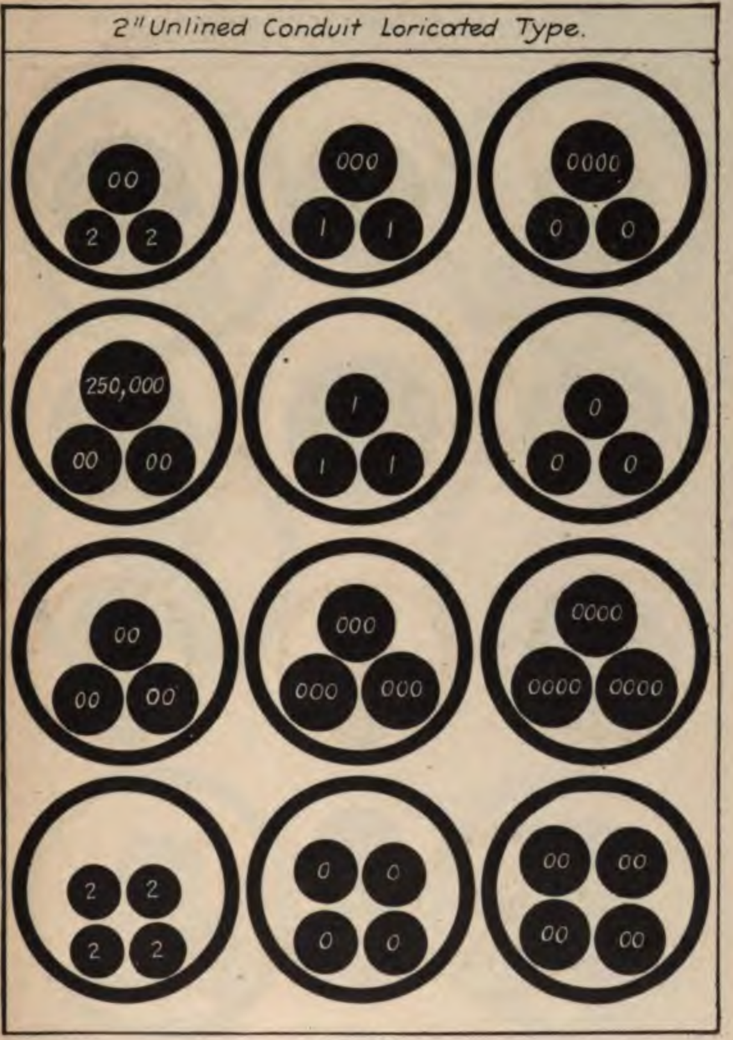

2" Unlined Conduit Loricated Type.
00
2
2
000
1
1
0000
0
0
250,000
00
00
1
1
1
0
0
0
00
00
00
000
000
000
0000
0000
0000
2
2
2
2
0
0
0
0
00
00
00
00

FIG. 111

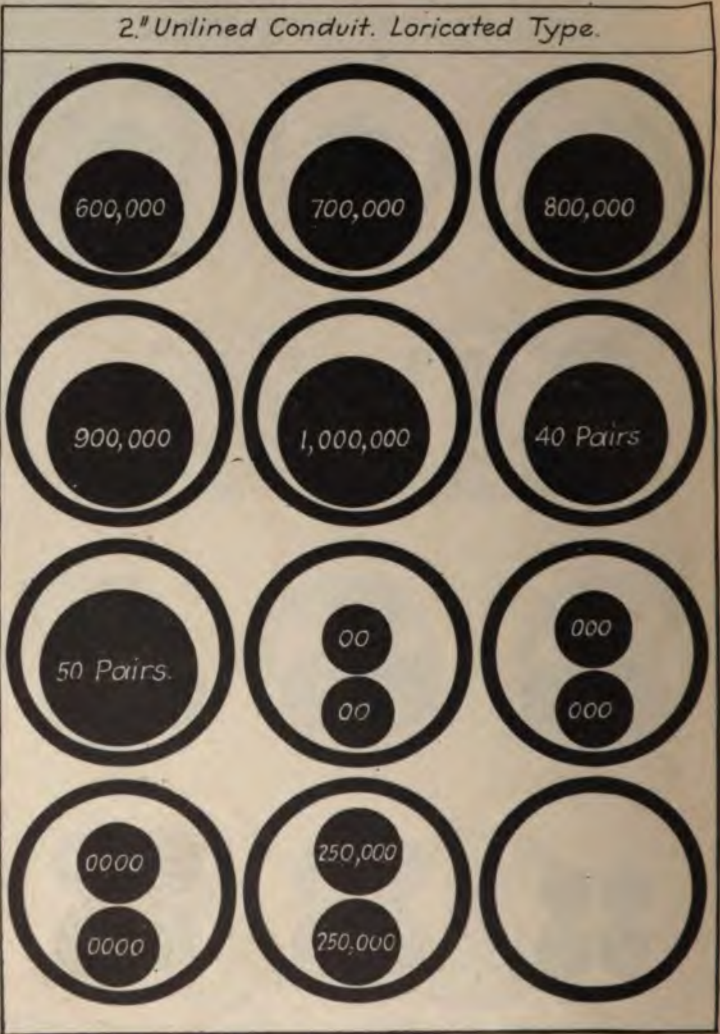

2." Unlined Conduit. Loricated Type.
600,000
700,000
800,000
900,000
1,000,000
40 Pairs
50 Pairs.
00
00
000
000
0000
0000
250,000
250,000

Fig. 112

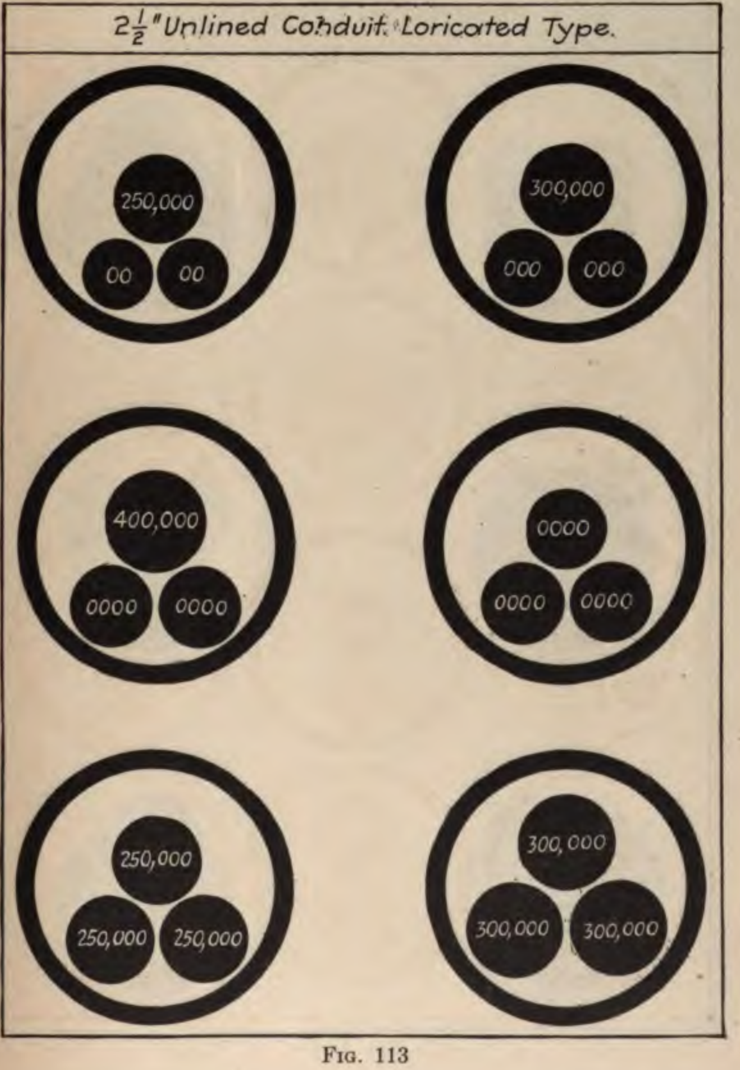

2½" Unlined Conduit. Loricated Type.
250,000
00
00
300,000
000
000
400,000
0000
0000
0000
0000
0000
250,000
250,000
250,000
300,000
300,000
300,000

FIG. 113


2½" Unlined Conduit. Loricated Type.
1,000,000
1,500,000
1,800,000
250,000
250,000
300,000
300,000
350,000
350,000

Fig. 114

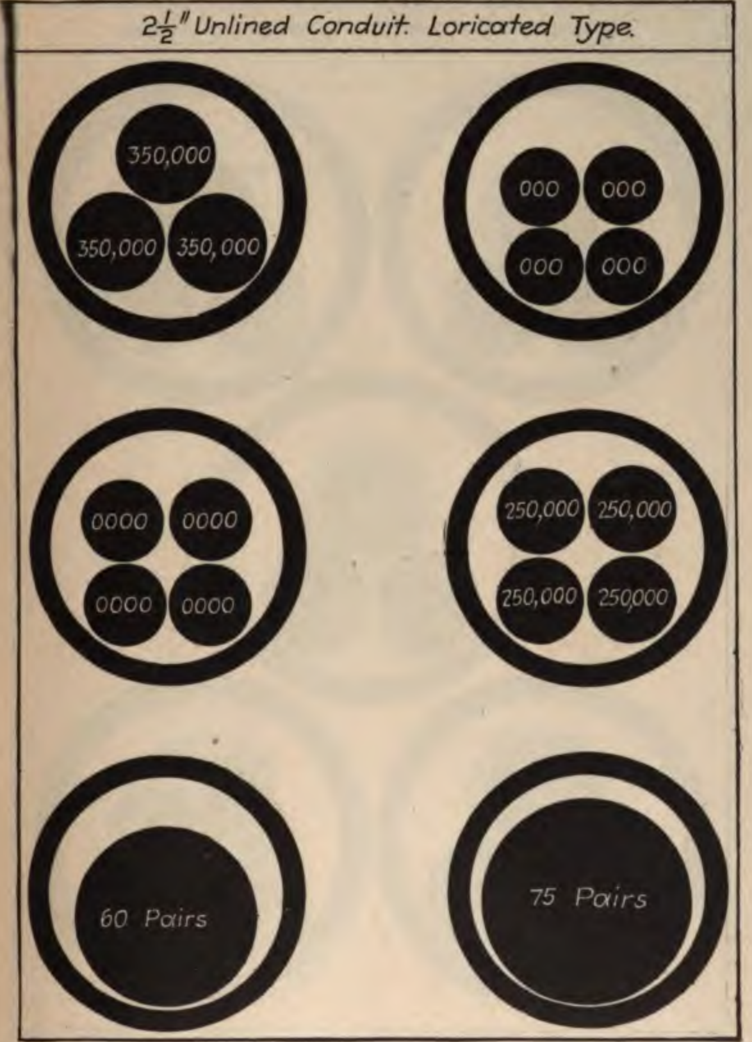

2½" Unlined Conduit. Loricated Type.
350,000
350,000
350,000
000
000
000
000
0000
0000
0000
0000
250,000
250,000
250,000
250,000
60 Pairs
75 Pairs

FIG. 115

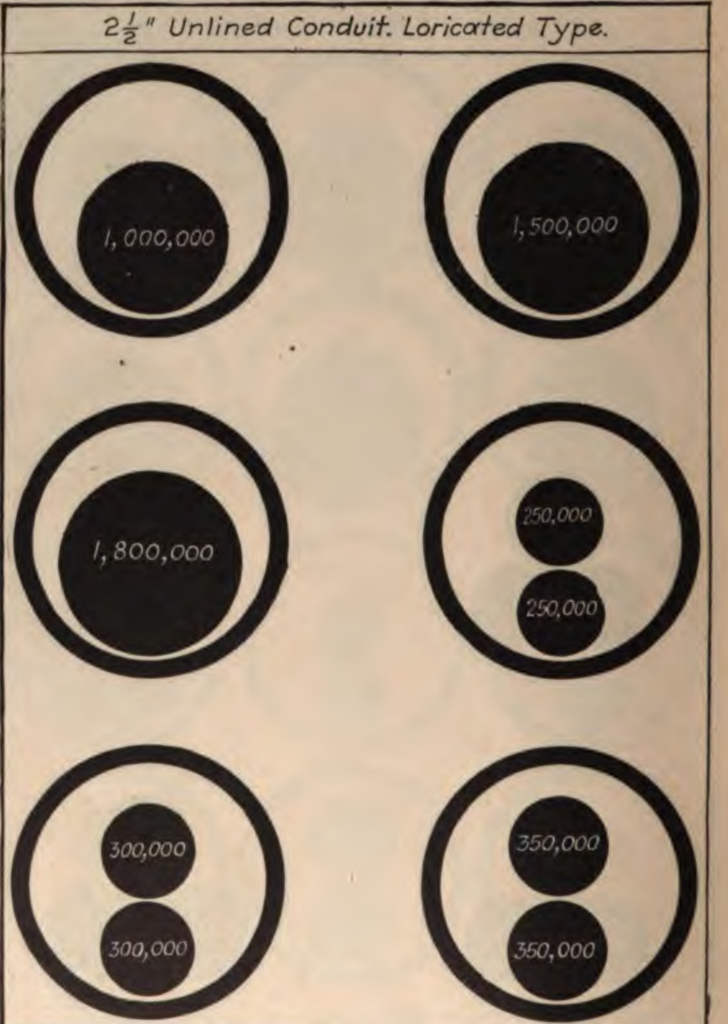

2½" Unlined Conduit. Loricated Type.
1,000,000
1,500,000
1,800,000
250,000
250,000
300,000
300,000
350,000
350,000

FIG. 114

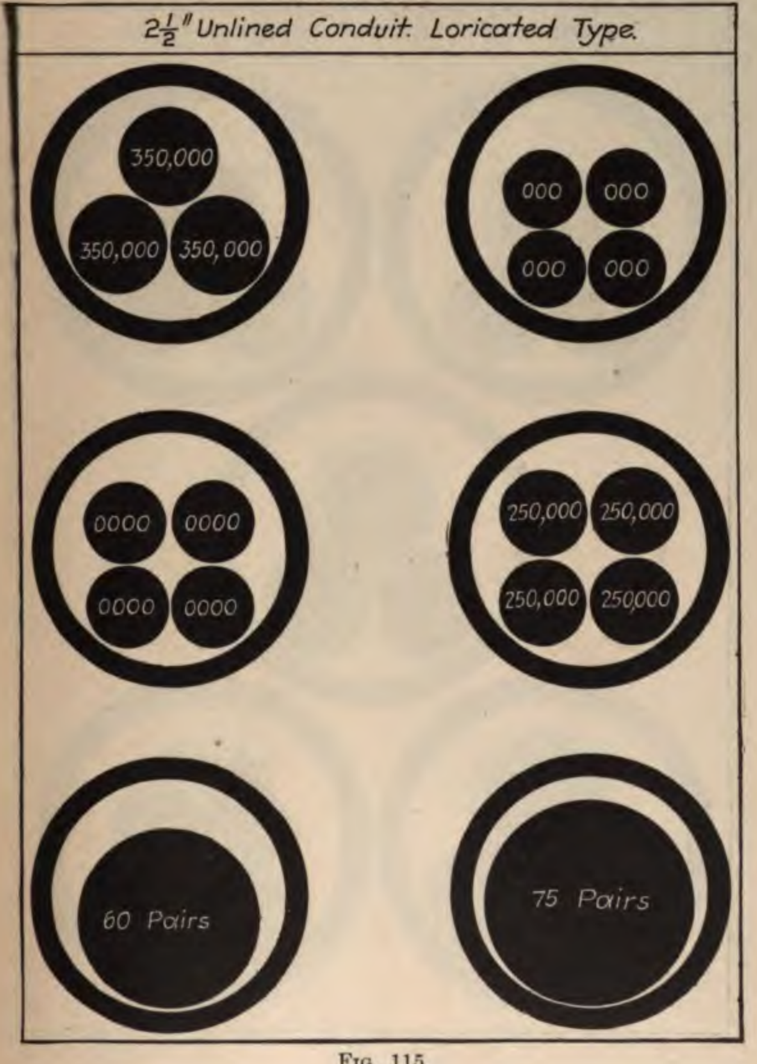

2½" Unlined Conduit. Loricated Type.
350,000
350,000
350,000
000
000
000
000
0000
0000
0000
0000
250,000
250,000
250,000
250,000
60 Pairs
75 Pairs

FIG. 115

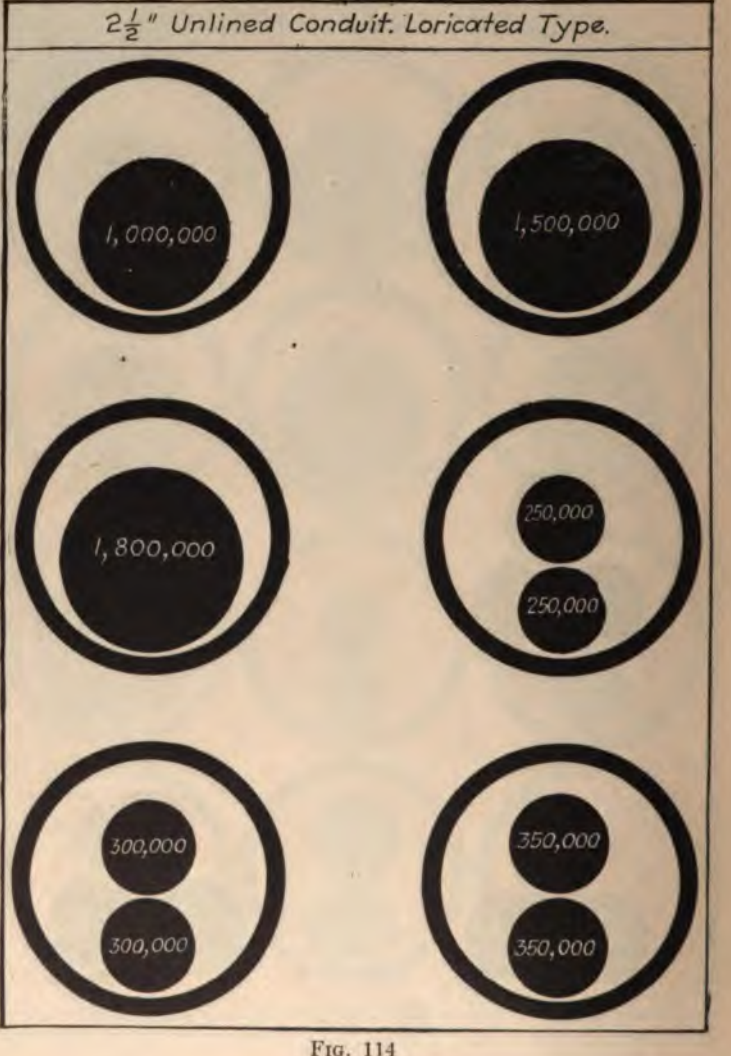

2½" Unlined Conduit. Loricated Type.
1,000,000
1,500,000
1,800,000
250,000
250,000
300,000
300,000
350,000
350,000

FIG. 114

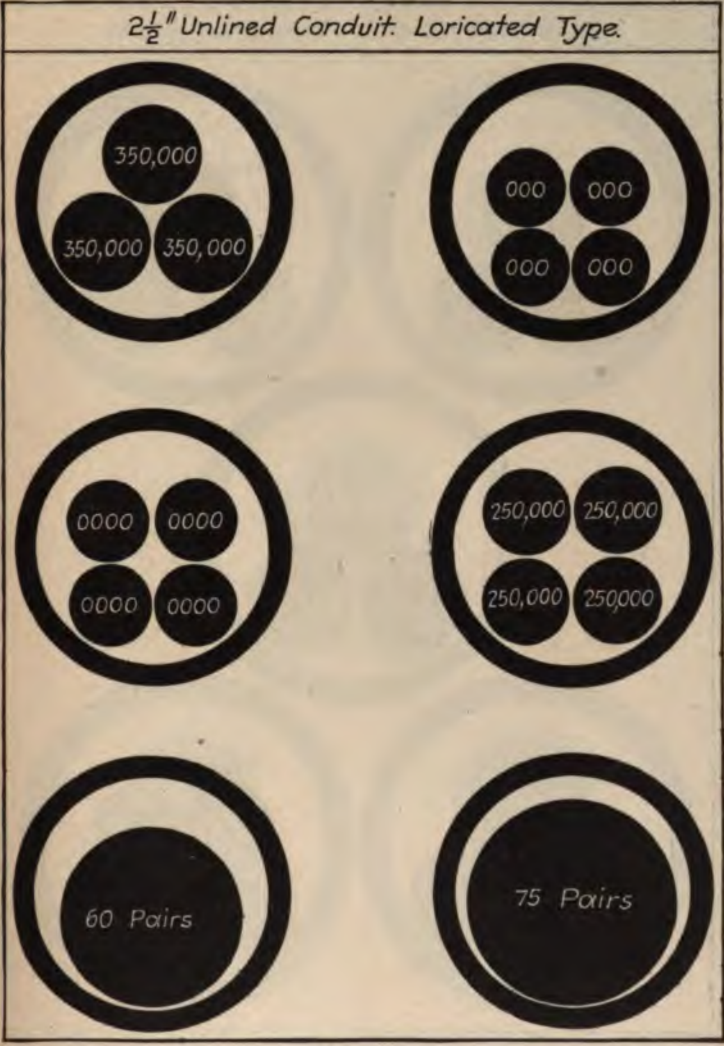

2½" Unlined Conduit. Loricated Type.
350,000
350,000
350,000
000
000
000
000
0000
0000
0000
0000
250,000
250,000
250,000
250,000
60 Pairs
75 Pairs

FIG. 115

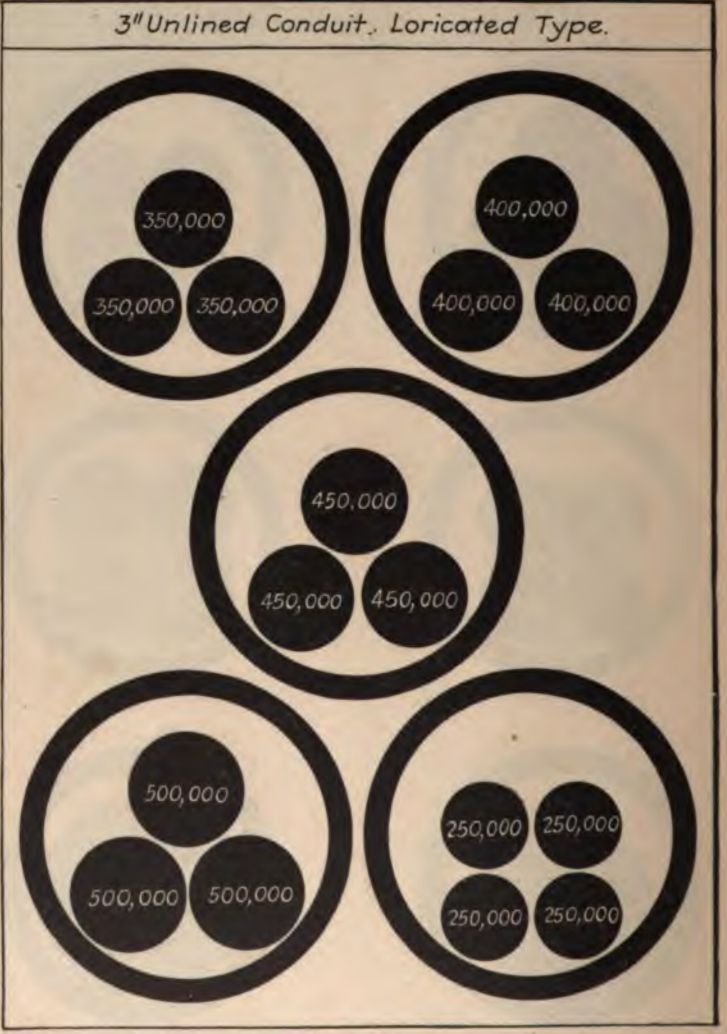

3" Unlined Conduit. Loricated Type.
350,000
350,000
350,000
400,000
400,000
400,000
450,000
450,000
450,000
500,000
500,000
500,000
250,000
250,000
250,000
250,000

FIG. 116

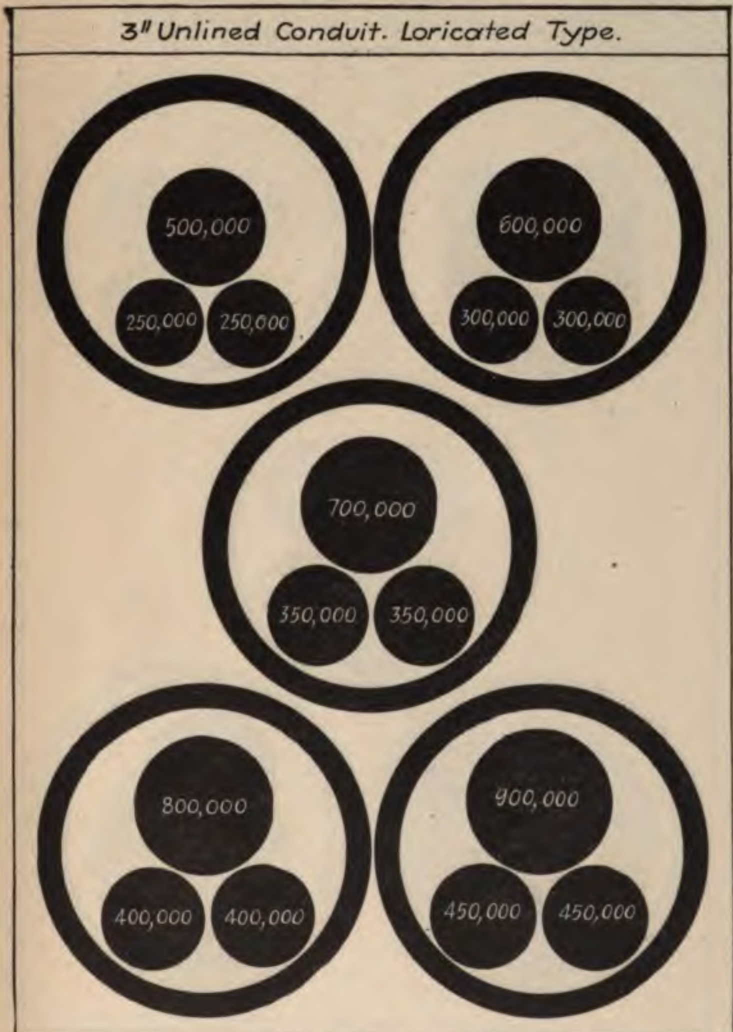

3" Unlined Conduit. Loricated Type.
500,000
250,000
250,000
600,000
300,000
300,000
700,000
350,000
350,000
800,000
400,000
400,000
900,000
450,000
450,000

Fig. 117

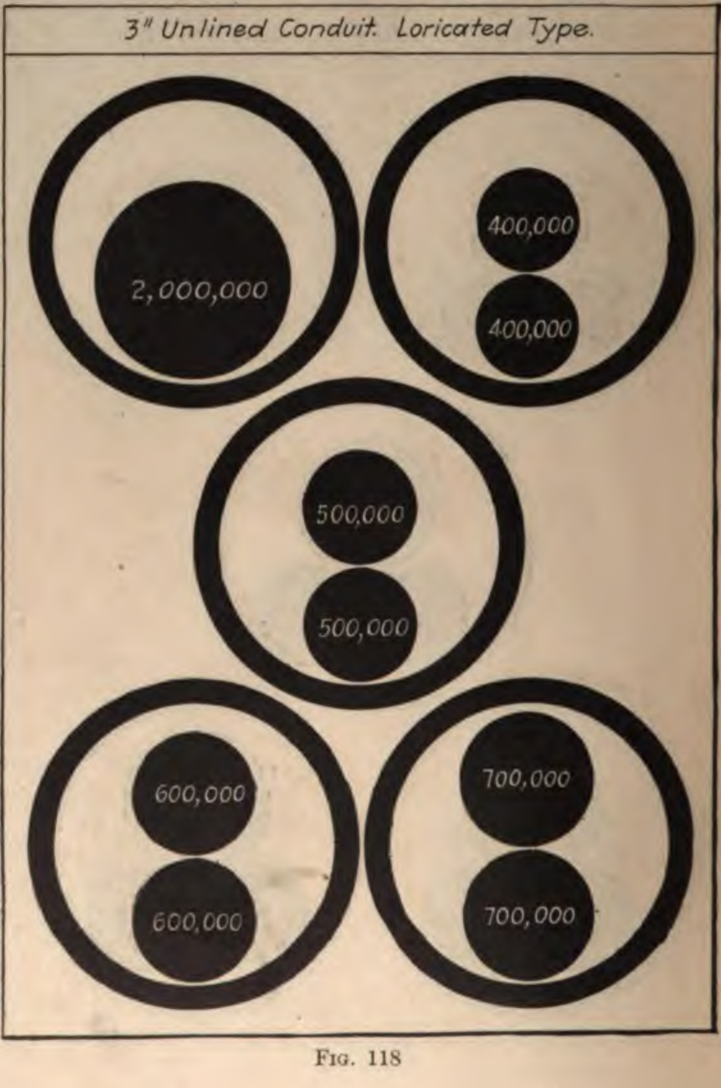

3" Unlined Conduit. Loricated Type.
2,000,000
400,000
400,000
500,000
500,000
600,000
600,000
700,000
700,000

FIG. 118

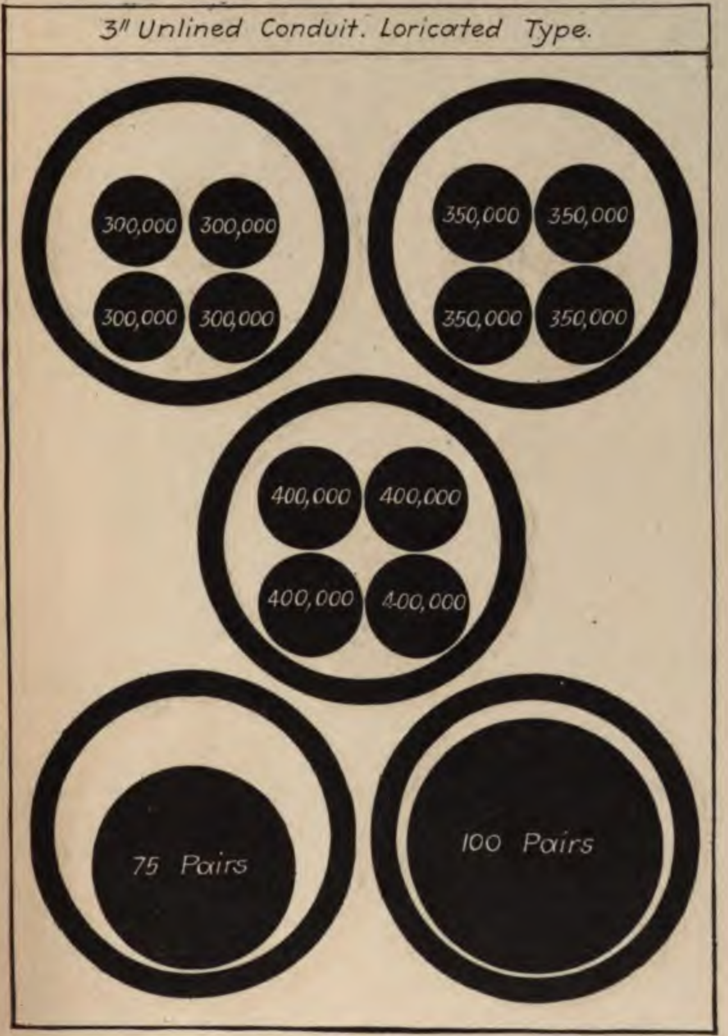

3" Unlined Conduit. Loricated Type.
300,000
300,000
300,000
300,000
350,000
350,000
350,000
350,000
400,000
400,000
400,000
400,000
75 Pairs
100 Pairs

Fig. 119